# Soil Disturbance Guidelines: Productivity and Administrative Implications

## Proceedings of the Penticton Workshop (April, 1990)

Edited by

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**December 1991**

BC
Ministry of Forests

93-02322/

Copies of this report may be obtained, depending upon supply from:

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**Citation:**

Chatwin, S.C. and S. Homoky. (Compilers). 1991. Soil disturbance guidelines: productivity and administrative implications. Proceedings of the Penticton workshop (April, 1990). B.C. Min. For. Victoria, B.C. Misc. Rep. 70 p.

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# OPENING REMARKS

Mike Wilkens

First, I would like to welcome you to the "Soil Disturbance and Site Productivity Workshop." Over the next two days, through both the formal presentations and your informal discussions, I hope you are able to improve your knowledge by learning what is happening in British Columbia in soil disturbance and site productivity.

Why should we be concerned with soil disturbance? There are three broad reasons:

- Any undesirable soil disturbance is likely to reduce the productivity of our forest sites. In this day and age when we are trying to maintain our level of harvest on an ever shrinking forest land base, we cannot afford such losses in productivity.
- Any undesirable soil disturbance may well result in an unacceptable level of soil erosion, and an undesirable impact on natural resources such as water and timber.
- Given the very high public concern over the environment, the public are not going to accept, in future, the types of harvesting practices which have led to losses in soil productivity and damage to water and fish values. We in the Forest Service and forest industry must respond to this public demand for improved forest management practices, or else face the consequence of a loss in public confidence and everything that implies.

I would now like to describe the role of the Interior Forest Harvesting Council and its various committees. The Council was formed in late 1987. Our concern was that we were not making quick enough progress throughout the interior of the province in reducing soil disturbance resulting from harvesting and silvicultural practices. We felt that if a committee of senior government and industry personnel could develop a process of discussion and education, guidelines on what is acceptable soil disturbance would result.

I presently chair the Interior Forest Harvesting Council. The committee consists of the five interior Regional Managers in the Ministry of Forests, industry representatives from the three Interior Lumber Manufacturers' Associations, and one representative each from Forestry Canada, B.C. Ministry of Forests' Research Branch, FERIC and the Technical Advisory Committee. Our main achievement to date has been the introduction in April 1989 of the Interim Site Disturbance Guidelines. We have also promoted a comprehensive literature survey of current soil disturbance and site productivity research results, a survey of the cost productivity and soil disturbance levels of various harvesting systems, and a 2-day seminar that addresses site sensitivity and soil disturbance assessment. This seminar is given throughout the province. In addition, we have promoted research projects in soil disturbance and site productivity.

When the Interior Forest Harvesting Council was established, Regional Subcommittees and a Technical Advisory Committee were also set up. The Regional Subcommittees, chaired by the Regional Managers, consist of ministry and industry personnel. These are really the working, operating arm of the Interior Forest Harvesting Council. Their job is to implement the policies and guidelines of the Council; to initiate research projects; to undertake soil disturbance training and education of ministry and industry staff; and to provide input to the Council. The role of the other advisory body to the Council, the Technical Advisory Committee, is to advise the Council on guidelines, procedures, research and training as they relate to soil disturbance.

The Technical Advisory Committee is chaired by Alex Sinclair of FERIC and consists of representatives from Research Branch, Timber Harvesting Branch, Silviculture Branch, Protection Branch, Forestry Canada and industry. This Committee in turn co-operates closely with the Site Degradation and Rehabilitation Working Group to review and comment on any guidelines or procedures being considered. The Site Degradation and Rehabilitation Working Group is a group established by Research Branch to develop and co-ordinate research throughout the province in the soil disturbance and site productivity areas. It consists of representatives from Research Branch, Forestry Canada and FERIC, and all the Regional Pedologists in the Forest Service.

Now that I have explained who the Interior Forest Harvesting Council and the other committees working in the soil disturbance and site productivity areas are, I would like to tell you what we plan to do next.

1. We propose to develop and implement interim guidelines on soil disturbance that results from site preparation and fire protection activities.
2. We intend to implement a standardized soil disturbance measurement system for the province.
3. We intend to implement a soil disturbance training module for skidder operators.
4. We will be promoting the allocation of funding from government and industry so that more research can be done on soil disturbance and site productivity.
5. We intend to establish a feedback mechanism to help us review the Interim Site Disturbance Guidelines by spring 1991.
6. We propose to review administrative procedures to ensure that the tools required to ensure compliance with site disturbance guidelines are in place.

In conclusion, I hope I have been able to explain the role of the Interior Forest Harvesting Council and its committees in dealing with soil disturbance and site productivity in the province; and to bring you up to date on what we have done and what we propose to do.

I am quite proud of what the Council has achieved since it was formed slightly more than two years ago. We have Interim Soil Disturbance Guidelines in place, and will soon have similar guidelines for fire protection and site preparation. This progress is a direct result of the spirit of co-operation and commitment brought to the Council by both government and industry people.

## KEYNOTE ADDRESS

# SUSTAINABLE DEVELOPMENT AND FORESTRY IN BRITISH COLUMBIA

Anthony H.J. Dorcey

Westwater is in the midst of a 2-year research project on water in sustainable development, using the Fraser River Basin as a case study. The objectives are to examine:

- the implications of putting evolving principles of sustainable development into practice; and
- the requirements for managing large river basin systems in sustainable development.

The presentation today draws on experience in carrying out this research and relates this to the sustainable development of forestry. I will begin by describing our approach to the definition of sustainable development. I will then relate this to well-established principles of water and forest management and the reasons why they have been so difficult to put into practice. I will argue that the principles of sustainable development are going to be even more challenging to put into practice. In concluding, I will suggest four sets of policy and institutional issues that will be critical to our success in putting sustainable development principles into practice — issues that are being examined in Westwater's research.

### Discussing Sustainable Development

People define sustainable development in many different ways, in part because the meaning of the concept is still being explored. Our project has, therefore, adopted the broad definition proposed in the widely discussed Brundtland report as a starting point, and is exploring the implications of different interpretations of this. Brundtland defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." We are considering sustainable development as an ethic that is still evolving and embraces values associated with environmental, economic and social systems. Minimal procedural and substantive elements of the ethic that are commonly discussed are:

- maintaining ecological integrity and diversity;
- meeting basic human needs;
- keeping options open for future generations;
- reducing injustice; and
- increasing self-determination.

### Implications for Water and Forest Management

To a large extent, these ideals of sustainable development have been part of espoused principles of water and forest management for at least a decade. They have been articulated under various labels including:

- "strategic watershed planning";
- "comprehensive river basin development";
- "integrated resources management"; and
- "sustained yield management."

These principles, however, have been extremely difficult to put into practice. Furthermore, sustainable development ideals are going to increase these difficulties greatly. New challenges will be created by the need to address:

- increased numbers of systems and subsystems;
- expanded spatial boundaries;
- lengthened time scales;
- greater demands on science;
- pervasive uncertainty;
- heightened ethical concerns; and
- greater need for consensus.

**Assessing Policies and Institutional Arrangements**

In assessing the adequacy of present policies and institutional arrangements for management, we are giving particular attention to four important issues in the present research program:

1. Political context: Even though legislation, policies and guidelines reflect elements of sustainable development principles, it is necessary to determine to what extent political commitment and resources exist to implement them in practice throughout the governance system.
2. Decision-making mechanisms: Implementation of sustainable development requires reform and integration of the four major decision-making mechanisms used in the governance of natural resources: Political-Legislative; Legal-Judicial; Bureaucratic- Administrative; and Economic-Market.
3. Information generation: The efficient generation of credible information that is essential to the implementation of sustainable development will require: major advances in the ways in which people are brought together to use analytical techniques; new priorities for identifying the analytical techniques with low costs and high benefits in information generation; and emphasis on the strategies for dealing with uncertainty and judgement in science and values.
4. Individuals' skill: Of fundamental importance to the above and other innovations required for success in implementing sustainable development is the need to improve the individuals' skills in co-operation and conflict resolution. This implies developing skills for effective communication, constructive argumentation, and productive negotiation and mediation.

It is in this larger context of sustainable development that the specific issues relating to soil disturbance guidelines need to be considered.

# A REVIEW OF HARVEST-RELATED SOIL DISTURBANCE RESEARCH IN BRITISH COLUMBIA

Gregory P. Kockx, R.P.F.

As early as the 1950's, research was conducted on the impacts of timber harvesting on forest soils in the northwest United States. In British Columbia, attention focused on the environmental impacts of logging in the early 1970's. Concern on the coast was mostly over fish-forestry impacts, and in 1972 these concerns resulted in coastal logging guidelines being implemented. To address the problem further, a number of studies were initiated, such as the Carnation Creek Project in 1972 and the Fish-Forestry Interaction Program in 1981. Results from these studies helped formulate the fish-forestry guidelines used today.

In the Interior, concern focused on the on-site impacts of harvesting — that is, the impacts on soil and site productivity. In 1973, concern over the amount of soil disturbance on steep slopes in the Nelson Region resulted in the Forest Service issuing guidelines which prohibited ground skidding on slopes over 70% and restricted it on slopes between 50 and 70%. Because much of the logging in the Nelson Region was in steep mountainous terrain — in fact, most of the unlogged merchantable timber was on slopes over 50% — and because over 95% of the logging was being done with ground skidding systems, the consequences of such guidelines to the industry were substantial. To address the problems of steep slope harvesting in the Nelson Region, a committee was therefore set up in 1974 with various government agency and industry personnel. The Steep Slopes Committee initiated several research projects.

The initial studies conducted in British Columbia were broad in scope and generated information on the extent, degrees and sources of disturbance for various logging systems (Bockheim *et al.* 1975; Utzig and Herring 1975; Smith and Wass 1976; Krag *et al.* 1986). They defined the nature of soil disturbance problems on steep slopes in the Kootenays and to a lesser extent in southwest British Columbia. Since these studies, research has shown that harvesting on steep slopes in other regions of the province has resulted in similar soil disturbance problems (McMorland 1980; Schwab and Watt 1981). Cable logging and ground skidding systems have been shown to disturb soils by varying degrees. Disturbance such as scalping, gouging, soil displacement, compaction and associated soil erosion can cause soil degradation (Utzig and Herring 1975), which results in reduced site productivity (Smith and Wass 1979). Table 1 summarizes results from several studies.

TABLE 1. Summary of soil disturbance levels

| Study | Season | % Disturbance by harvesting method[a] | | | |
|---|---|---|---|---|---|
| | | Ground skidding | | Cable logging | |
| | | Average | Range | Average | Range |
| Smith and Wass 1976 | Summer | 46 | – | 22 | – |
| | Winter | 26 | – | 17 | – |
| Krag *et al.* 1986 | Summer | 45 | 29–65 | 30 | 22–40 |
| | Winter | 40 | 14–52 | 22 | 12–28 |
| Bockheim *et al.* 1975 | Summer | 70 | 68–71 | 29 | 5–71 |
| Schwab and Watt 1981 | ALL | 44 | 35–60 | 12 | 9–17 |
| Smith 1988 | ALL | 58 | 17–61 | | |

[a] Disturbance levels are the proportion of harvested area with exposed mineral soil for all studies except Smith (1988), in which only gouges or deposits greater than 10 cm in depth were measured.

Although survey methods sometimes differed and disturbance levels varied between studies for similar systems, the studies showed common trends. The major findings of this research are summarized as follows:

- Ground skidding systems cause more soil disturbance than do cable systems;
- Summer logging results in more soil disturbance than does winter logging;
- The major source of disturbance is skidroads, followed by haul roads, and then landings;
- Most deep disturbance results from haul roads, landings and skidroads. Off-road disturbance is mostly shallow; and
- Harvesting systems produce a wide range in disturbance levels.

With the relationship between harvesting systems and soil disturbance better understood, research began to focus on methods of reducing disturbance levels through the use of alternative logging systems. Non-conventional ground skidding practices have been compared to conventional systems to assess their economic and environmental viability. Small crawler tractor systems, for example, have been shown to cause less disturbance than conventional systems and still be operationally competitive (McMorland 1980; Krag and Webb 1987).

Results and recommendations from research into harvest-related soil disturbance have helped the B.C. Ministry of Forests to formulate the soil disturbance guidelines it recently introduced.

Harvesting research is continuing to focus on methods of reducing the extent and severity of soil disturbance (e.g., through the use of designated skidtrails and wide-tired skidders), assessing the effect of these methods not only on soil disturbance levels, but also on costs and log production — all important considerations if such practices are to be introduced operationally.

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# SITE SENSITIVITY INTERPRETATIONS FOR TIMBER HARVESTING TO MINIMIZE DEGRADED SITES

Terence Lewis

To meet the requirements of legislation, policy, and the Interior Forest Harvesting Guidelines, we need a package of strategies that allow us to harvest timber without causing excessive site degradation and corresponding losses in long-term forest productivity. We can achieve this goal by having:

1. an objective process with which to assess the relative sensitivity of a site to degradation; and
2. a range of alternative and workable strategies with which to modify timber harvesting practices to suit the varying degrees and types of sensitivity.

Today, I will restrict my presentation to the first item.

**Requirements for Effective Sensitivity Assessment**

To be effective, a sensitivity assessment process should:

- be objective and reproducible;
- allow the user to understand the cause of the sensitivity, as well as the level of sensitivity;
- be soundly based; that is, be derived from an understanding of the mechanisms of degrading processes and their controlling factors;
- be practical and workable, involving a reasonable amount of field time; and
- fit into the existing planning process, using data already collected.

As well, the evaluation itself should suggest ways of dealing with the site limitations.

**Degradation Sensitivity**

Site degradation is the lowering of the long-term productivity of a site by management activities. By contrast, disturbance is any abrupt change in the physical, chemical or biological properties of a soil or site. Depending on the appropriateness and quality of the practices applied, sites may be degraded during logging (or mechanical site preparation) as a result of soil compaction, soil puddling, soil displacement, surface soil erosion, mass wasting, hydrology changes, nutrient export, and microclimate alteration. All but the last of these tend to be strongly affected by the actual logging system (equipment and logging practices) applied — the last more so by the silvicultural system (cutting methods).

Most of these aspects of degradation sensitivity are covered by the following four hazard keys:

1. Compaction Hazard Key (includes puddling);
2. Displacement Hazard Key (includes some slope hydrology changes);
3. Surface Erosion Hazard Key; and
4. Mass Wasting Hazard Key.

Each of these processes is defined, controlling factors are outlined, and the hazard key is presented and explained. This closely follows pages 4–11 of the Land Management Handbook, Field Guide Insert, "Developing Timber Harvesting Prescriptions to Minimize Site Degradation: Interior Sites."

For planning and policy purposes, it is useful to develop an overall degradation sensitivity rating that integrates the various individual degradation hazards. Using the highest hazard rating would be overly

simplistic because it does not consider the balance between on-site and off-site impacts, the potential to manage for **potential hazards** to minimize **actual impacts**, or the potential or lack of potential for site rehabilitation. Since the high displacement hazard is invariably the most limiting degradation hazard of organic soils, **the overall degradation sensitivity of organic soils is high**.

For mineral soils the Overall Degradation Sensitivity Class equals the highest of:

- Mass Wasting Hazard Class;
- Displacement Hazard Class;
- Compaction Hazard minus one class; and
- Surface Erosion Hazard minus one class (note exceptions below).

Mass wasting and displacement hazard classes are used directly in determining a site's overall degradation sensitivity because:

- management options are largely restricted to avoidance;
- the effectiveness of rehabilitation is limited; and
- for mass wasting, off-site impacts are often substantial.

A lower weighting is assigned to compaction hazard because a range of management options (equipment, scheduling) are available, compaction does not directly produce off-site impacts, and rehabilitation of compaction is feasible. In most situations, surface erosion hazard is lowered one class in deriving overall degradation sensitivity because the hazard rating assumes the removal of forest floor layers, which does not commonly occur over large, continuous areas during logging; and, where mineral soils are exposed, a range of rehabilitation options (e.g., waterbarring, seeding, silt-fencing) are available. The surface erosion hazard should be used directly where sediment delivery potential is high or watershed sensitivity is high because of water quality or fisheries concerns. For practical purposes, high sediment delivery potential is defined as existing where two or more watercourses (ephemeral, intermittent or permanent) occur per 100 m along the contour.

### Overall Site Sensitivity

For perspective, keep in mind that degradation sensitivity is only one of several factors that influence the overall sensitivity of a site to timber harvesting. Other factors include water, fisheries, wildlife, visual/aesthetic values and, economic and social concerns. Although degradation sensitivity is an on-site concern, the off-site consequences of site degradation are strongly related to watershed and aesthetic sensitivity.

### Prescription Formulation

The above outlined site sensitivity evaluation fits very well into the existing Pre-Harvest Silviculture Prescription process (PHSP). The data required to employ the four keys effectively is, for the most part, already collected during PHSP's. Consequently, this evaluation is considered to be an integral part of formulating harvesting prescriptions that are ecologically appropriate, economically realistic, and professionally ethical.

## SUMMARY OF SITE PREPARATION IMPACTS ON SOILS

Lorne Bedford

The role of site preparation in British Columbia's reforestation program has increased significantly in the past several years (Figure 1). During the ten-year period from 1980 to 1989, over 1.1 million hectares of Crown forest land were site prepared. Mechanical site preparation is particularly topical when one is considering soil disturbance guidelines, and it will be the main focus of this paper.

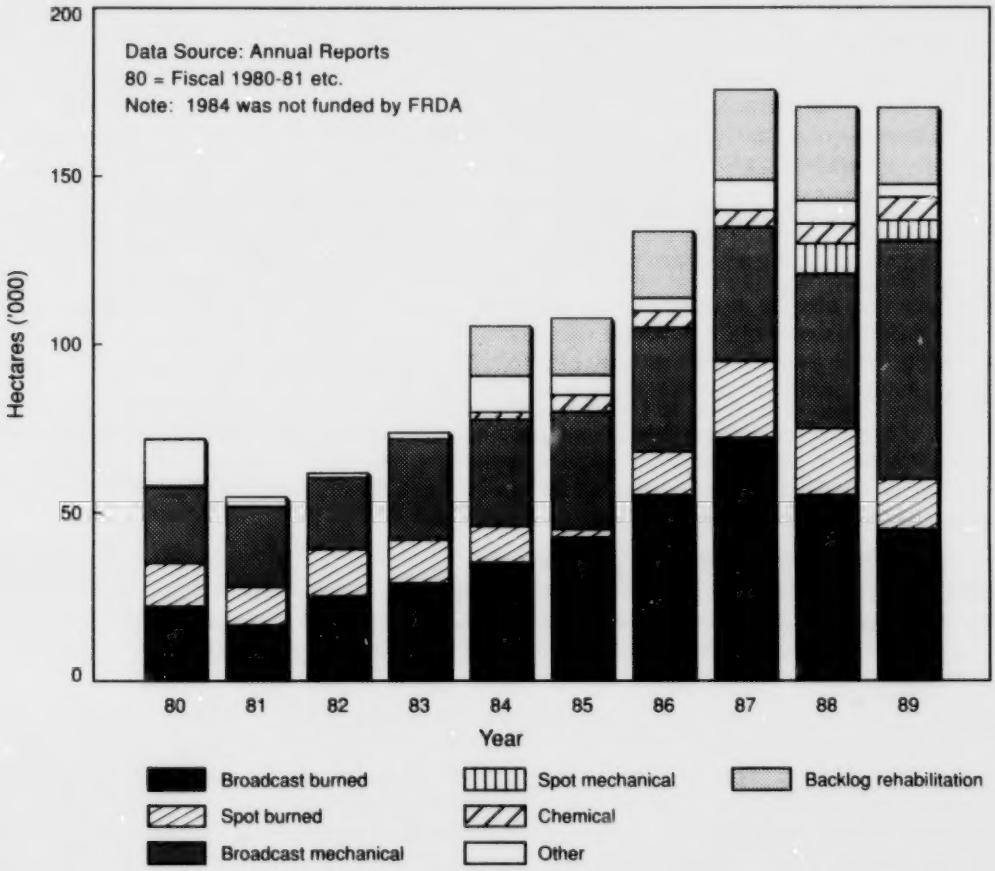


FIGURE 1. Total area of site preparation on Crown land from 1980–89 for British Columbia.

The effect of mechanical site preparation on site productivity varies by site, treatment type and treatment intensity. This paper will be limited to two topics which are closely related to site productivity: compaction and nutrient removal.

Compacted soil affects site productivity in several ways. Compaction may decrease site productivity by hindering optimum root development. While root growth for certain species may persist in soils with bulk density values as high as 1800 kg $m^3$ (Forristall and Gessel 1955), for the range of soil types and tree species in British Columbia, tree root growth will generally be reduced when soil bulk density values exceed a threshold range of 1200–1400 kg $m^3$ (Lousier 1990). As well, the hydrology of compacted sites may also affect site productivity. A compacted, poorly drained site may be subject to flooding in the spring, followed by moisture deficits later in the growing season. Severely compacted soil also hinders planting, particularly if soils are dry.

Soil compaction may be introduced by events such as harvesting or site preparation. However, naturally occurring soil densities may also exceed optimum levels for forest growth. Site preparation has long been seen as a means of reducing compaction. In England, Pontey (1808) recommended treating shallow clay soils by drawing soil to the base of trees to increase rooting depth. More recently, ripping has been used to loosen deep layers of compacted soil (Ritchie 1965).

The effectiveness of ripping as a means of alleviating soil compaction depends on the type of ripper being employed, as well as the type of soil being treated. Andrus and Froehlich (1983) found a winged subsoiler to be much more effective in reducing compaction than a standard rock ripper or brush blade. Similar results have been reported for landing rehabilitation trials in British Columbia. For example, based on a 30 cm desired average ripping depth, profile shatter for a self-drafting winged subsoiler was 137% (Carr 1990). This result far exceeded the 26% shatter previously obtained with standard rippers on similar soil (Carr 1985). Generally, ripping is more effective on coarser textured, non-cohesive soils (Andrus and Froehlich 1983; Carr 1990). It must also be noted that subsoiling is not a "cure-all." On sites where organic matter has been severely depleted, the benefits of subsoiling are often temporary and nutrient levels remain low (Carr 1990). In such cases, subsoiling must be supplemented by some form of organic matter management.

In B.C. the self-drafting winged subsoiler has generally been used for rehabilitating compacted landings and skidroads. In trials where the subsoiler has been used on cutblocks, treatment quality and productivity have been very sensitive to slash loading and stump frequency (De Long *et al.* 1990).

Soil density may also be reduced by other methods of site preparation which mix organic material with mineral soil. In British Columbia, the Madge rotoclear and the Eden relief bedding plow have both provided excellent mixing. While these treatments have proven to be particularly effective in reducing compaction (Butt and Bedford 1990), operational use is limited by site and cost.

Reduced site productivity caused by the removal of nutrients is a concern associated with both harvesting and site preparation. In site preparation, nutrient removal varies as a function of treatment method and treatment severity. The impact nutrient removal will have in reducing site productivity depends on factors such as site fertility, soil type, and nutrient input into the forest system.

Blade scarification is a method of site preparation that is commonly associated with nutrient removal. On certain sites the benefits associated with this treatment (e.g., increased soil temperature) may outweigh losses associated with nutrient removal. Other sites may be particularly sensitive to nutrient removal, and the cost to site productivity may outweigh any benefits associated with the treatment, particularly when treatments are severe (Ball 1990).

Particular care must be taken in the scarification of certain soil types. The removal of surface organic material which exposes wet, fine-textured soils can severely decrease seedling growth (McMinn 1985). Similarly, scarification which exposes dense subsoils may result in reduced seedling performance (McMinn *et al.* 1990). Scarifying sandy soil may also result in the reduction of long-term site productivity. Organic matter is particularly important in sandy soils where even small amounts of organic material can significantly improve water retention properties and increase the ability of the soil to hold and exchange nutrients (Brady 1974). When the organic content of sandy soils is reduced by scalping, restoring the site to its original potential is often a very slow process (Ezell and Arbour 1985).

In many cases (e.g., over-scarification), the potential for site degradation is obvious. In other cases, it may be subtle and visual detection may be difficult. The rate at which organic nitrogen and other nutrients are converted to available mineral forms depends on microbial activity. Increasing soil temperature generally stimulates microbial activity, increasing nitrogen mineralization and, ultimately, available nitrogen (Brady 1974). The mineralization of nitrogen can be further stimulated by the mixing of mineral soil and humus (Salonius 1983). Increasing the amount of available nutrients on a site may be highly desirable if the mineralization of nutrients covers the needs of the seedling. However, if the mineralization process is too rapid, nutrients which are not used may leach from the site, decreasing long-term site productivity (Malkonen 1987). The loss of nutrients associated with rapid mineralization may be particularly significant in less fertile, dry, coarse-textured soils (Squire and Flinn 1981; Lundmark 1983). Initially such sites may appear to benefit from intense site preparation, but promising early growth may diminish over time (Wilhite and Jones 1981; Örlander *et al.* 1990).

When determining the role site preparation will play in long-term site productivity, the forester must not consider site preparation in isolation nor view the ecosystem as static. Choice of harvesting method, for example, will influence the amount of nutrients remaining on a site before site preparation. Research from the Georgia Piedmont indicates that whole tree harvesting may remove 2–4 times the nutrients per unit biomass than conventional harvest (Gaskin *et al.* 1989). The same project indicated that site preparation by shear-pile and disk removed 2–7 times the amount of nutrients as chop and burn. The need to match the harvesting and site preparation method to the total nutrient capital of the site was emphasized. On the other hand, over time, inputs into certain ecosystems may tend to offset the nutrients lost during harvesting or site preparation. In the Prince George Forest Region for example, it has been noted that aspen (*Populus tremuloides*) plays a significant role in "rebuilding" forest ecosystems (J. Revel, M. of F., pers. comm.). Nitrogen fixation by alder (*Alnus viridis*) has also been noted to improve the growth of adjacent white spruce (*Picea glauca*) (Ballard and Hawks 1989). In southern Sweden the nitrogen shortfall on certain sites is offset by nitrogen supplied via air pollution (Lundmark 1983).

The importance of maintaining or enhancing site productivity during the site preparation phase of regeneration cannot be overstressed. To assist in this process, the Ministry of Forests is developing guidelines for site preparation similar to the interim guidelines which have been developed for harvesting. The interim guidelines for site preparation will be field tested during the 1991 field season. Guidelines will assist in preventing site degradation, however, there is no substitute for experience and personal commitment. In site preparation for reforestation, the old proverb "as much as necessary but as little as possible" provides an excellent working guideline.

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# RELATING TREE GROWTH TO SOIL DISTURBANCE

Richard E. Miller and J. Daniel Lousier

At issue is sustainable forestry. Sustainable forestry implies a non-ending series of actions to harvest, regenerate, and tend successive stands of trees. Each action or practice has a potential positive, neutral, or negative effect on site productivity. The net effect of these individual actions in each rotation and in a series of rotations is their cumulative effect. To sustain forestry, we must maintain or enhance the capacity of the land to produce desired crops at consistent levels of quality and volume over hundreds of years.

Forest site productivity depends on many factors including soil, climate, tree species, stand density, silvicultural practices, time, and their interactions. It is important to recognize that the effect of one factor on productivity may be enhanced or counterbalanced by changes in other factors. For example, reductions in soil quality because of soil disturbance might be compensated for by silvicultural practices that alter tree species, stand density, competing vegetation, or nutrient availability by fertilization. Thus, to isolate the effects of soil disturbance, one must specify, hold constant, or separate the effects of silviculture and climate. This isolation is nearly impossible to do, even in controlled experimentation. Hence, researchers resort to mathematical modelling.

The long-term consequences of soil disturbance (displacement, compaction, or loss) to sustainable forestry is uncertain, yet potentially critical. We especially need to know the effects of heavy equipment used in harvesting and site preparation on subsequent survival and growth of individual trees and, more critically, on stand growth per hectare and within sustained yield units.

Predictions of tree and stand growth after soil disturbance can be based on direct and indirect evidence. Direct evidence results when we measure and compare growth of trees and stands after forestry practices are applied at specified intensities. For example, measurement of growth after harvest by ground skidding using wheeled versus tracked equipment, or after ground skidding versus cable skidding, can provide direct evidence. Clearly, such comparisons must be made on many sites at differing times of year (or soil moisture conditions), and with differing equipment operators and harvest volumes, so that valid generalizations can be made for specified harvest and site conditions.

Because tree species frequently differ in their response to environment and treatment, research and predictions would have to specify species and accompanying silviculture (for example, vegetation control, regeneration method). When measurements are restricted to response of individual trees, then the link to stand response per hectare must be provided or predicted. Few will contest that direct evidence of stand response collected over such a broad scope of harvesting activities, site conditions, and operators, is necessary for valid predictions. And few will contest that such predictions should hold for the longer term, for cumulative effects, for interactions with other practices, and for possible changes in climate. Our review of the literature indicates that little direct, quantitative evidence is available and what there is represents short-term response of individual trees and not stands. Because the results are frequently conflicting, the need for more and more definitive research is clearly indicated.

Predictions of tree and stand growth after soil disturbance can also be based on indirect evidence. This can be presumptive (*a priori*) reasoning, as well as that derived from statistical analyses. Soil scientists, for example, frequently use *a priori* reasoning when they predict reductions in root (and, hence, tree growth) after they have measured or observed soil compaction. These measurements or observations, coupled with the general knowledge that compaction (1) reduces large pore spaces and, therefore, the movement of air and water in the soil and (2) increases physical resistance of soil to root expansion, lead observers to predict reduced tree growth. In some soils, some climatic conditions, and some tree species, such predictions of reduced growth are reliable. In other situations, they are not. In short, uncertainty and valid disagreements will persist until additional and more reliable investigations are performed.

Statistical analysis and mathematical modelling can extend direct evidence and improve *a priori* predictions. Application of statistics can quantify the relation between measured tree growth and measured soil disturbance. This can result in statistically valid, quantitative equations and statements describing the response of trees to increasing soil disturbance. Such statements are biologically valid only for the specific conditions (soil, climate, silviculture, stand age, etc.) of the investigations. More complex application of mathematics can model or describe the interacting effects of numerous factors that compose a system.

Forest practices affect the forestry system or ecosystem that is theoretically unique to each site. The ecosystem will respond to these practices. We need to know why and how much. Although statistics can provide useful means of obtaining more information and quantitative predictions from direct evidence (measured growth and measured disturbance), our literature review suggests that these analytical tools have had limited use.

Forecasts of timber yields often assume that inherent site productivity will be maintained or enhanced by intensive forest management. Is this assumption realistic? If so, for how long? Timber harvest levels may, in fact, be sustained or increased despite reductions in soil quality through the substitution of silvicultural practices such as fertilization and thinning. In the final analysis, however, the comparative costs of soil conservation versus soil substitutions must be evaluated. In short, the effects of forest operations on site productivity must be evaluated so that we can reduce the uncertainty among the forestry community and public at large.

# REVIEW OF SITE PRODUCTIVITY RESEARCH

R.B. Smith

## Methods of Collecting Data

Data on the effects of forestry operations on site productivity can be collected in a number of ways. **Retrospective** studies greatly shorten the length of time needed to obtain results, but they lack important environmental and stand history data and do not allow control of variables. **Synoptic** studies are essentially a series of retrospective examinations over a range of ages since stand establishment, and are especially useful for determining trends in development over long periods of time. A requirement for both methods is that the boundaries of the disturbance remain distinct for many years. Synoptic studies are affected by variation in site and may be complicated by climatic cycles.

**Soil-disturbance plantations** can solve many of the disadvantages of the two previous systems, but require a long time to produce results. This method allows the researcher to control species, spacing, disturbance category, and vegetation. Trees can be staked and planting spots described after operational planting, or trees can be planted on specific disturbance categories (e.g., a skidder track). Particularly for random skidding, knowledge of the degree of trail use is essential and should involve the number of skidder passes. To gain further control of the level of disturbance, the researcher can move away from operational situations and establish trials with a range of specified machine/soil interactions.[1] The ultimate aim in this regard is to produce artificially the soil conditions — such as a range of soil density — on which plantations are established.[2] All of these methods described depend on comparisons with tree performance on an undisturbed control area. We need to develop the ability to define and detect changes in site quality on the basis of soil and site properties alone.

## Nature of Problem

The selected research approach will depend in part on the perceived nature of the soil degradation problem. Most studies in our area have dealt with determining the impact of specific disturbed spots, such as skidroads and landings, on soil quality. The problem of an overall reduction in productivity caused by removal of biomass has received less attention even though the problem has been documented in other areas. In a review of productivity problems in the Pacific Northwest, Miller *et al.* (1990) state that harvesting most of the bole will not greatly deplete nutrients, but that a combination of short rotations and removal of branches and foliage may diminish nutrient reserves. If this occurs, then our "undisturbed" comparisons will not reflect the full detrimental impact of harvesting operations. Additional methods of study will have to be employed, involving a range of levels of biomass removal.

## Early Productivity Research

Some of the earliest work on soil degradation was conducted in the Pacific Northwest. Steinbrenner and Gessel (1955) found a 20% reduction in growth of 2- to 4-year-old Douglas-fir growing on skidtrails. Youngberg (1959) found that 2-year-old Douglas-fir grew 43% less on skidroad surfaces and 24% less on sidecast surfaces than on those undisturbed. This pattern across skidroads has since been noted in other areas. In coastal British Columbia, early work by Willington (1968) showed that Douglas-fir planted 10 years previously on skidroads were reduced by 16–34% in height and 25–43% in diameter growth compared with off-road trees. Similar reductions were found for Douglas-fir growing on access logging roads. These studies probably effected a reduction in the use of access and ground-skidding systems in coastal areas.[3]

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[1] Rollerson, T.P. 1989. 1988–1989 progress report on Buckley Bay mechanized harvesting seedling survival and growth study. MacMillan Bloedel Ltd., Woodlands Service Division, Nanaimo, B.C. 19 p. Unpublished report.

[2] Powers, R.F., D.H. Alban, G.A. Ruark, A.E. Tiarks, G.B. Goudy, J.F. Ragus, and W.E. Russell. 1989. Study plan for evaluating timber management impacts on long-term soil productivity: a research and national forest system cooperative study. U.S. For. Serv. 21 p. Unpublished report.

[3] Packee, E.C. 1969. Access logging: Research Project Report, Project E69-7, MacMillan Bloedel Ltd., Forestry Division. 3 p. Unpublished report.

A shift in emphasis to the Interior occurred in 1973 when the B.C. Forest Service issued guidelines restricting ground skidding operations in the Nelson District (now Region). Our own retrospective studies, done under the aegis of the Nelson Steep Slope Committee on 7- to 20-year-old stands (Smith and Wass 1979, 1980), showed similar patterns of growth on skidroads as those found by Youngberg (1959), namely, poorer growth, on the inside and better on the outside portion of skidroads. However, we also had sites that showed better height growth on the skidroads than on the adjacent undisturbed ground. Of 24 species and site combinations, 15 showed reduced growth on skidroads, 8 showed enhanced growth and 1 showed no difference. Part of the enhanced growth was likely due to the reduced level of vegetative competition on skidroads and also, particularly on cold, north-facing slopes, to increased summer soil temperatures. Because of different responses of sites to disturbance, we made an early attempt to rate the sensitivity of sites (Smith and Wass 1980). Prime factors were soil acidity, soil texture and depth, and climatic zone. Sites considered most sensitive were those with calcareous, coarse-textured or shallow soils in wet climates. Sites least sensitive were those with moderately acid, moderately coarse- to medium-textured soils in dry climatic zones. As you have heard today (Lewis 1990), a more refined rating system has been produced by the Timber Harvesting Subcommittee of the Interpretations Working Group. This system is now an underpinning of the recently released harvesting guidelines.

Retrospective and synoptic studies have provided information on the productivity of landslide scars. Miles *et al.* (1984) reported a 38% reduction in the growth of Douglas-fir established on 6- to 28-year-old landslides in Oregon. Stand volumes were 70% less on 30- to 60-year-old landslides in the Queen Charlotte Islands when compared with logged areas in the same age class (Smith *et al.* 1986).

**Recent Productivity Research**

It is only recently that retrospective studies have been revived. Thompson *et al.* (1990) reported on studies on Engelmann spruce in two sites in the Nelson Region in which growth patterns across skidroads showed the typical reductions in growth for trees growing on the inside portions of the surface. Work on lodgepole pine on three sites was recently conducted through a contract funded by Crestbrook Forest Industries.[4] On two sites with non-calcareous soils there were no significant differences in the growth of lodgepole pine on skidroad and undisturbed surfaces. On the third site, which had calcareous soil at a depth of around 30 cm, reductions in the height growth of lodgepole pine ranging from 14 to 25% occurred right across the skidroad profile. These results, our own limited sampling of lodgepole pine (Smith and Wass 1980), work in south-central Washington (Froehlich *et al.* 1986), and observations by foresters point to a possible greater adaptability of this species to disturbed soil.

Results are just starting to emerge from our 1- to 8-year-old soil disturbance plantations. They now consist of four plantations on stumped areas, two near constructed skidroads, and one in an area of random skidding. About 12 000 trees were originally planted. Of 54 site/species/disturbance category comparisons, 41 (76%) show reduced height growth (average of 18%) on disturbed versus undisturbed soil. Twenty percent show enhanced growth (average of 12%) on the disturbed soil. Responses to disturbance have been shown to vary greatly from site to site. Growth on a low clay content, well-drained, gravelly sandy loam soil disturbed by a stumping operation was enhanced, compared with growth on adjacent undisturbed ground (Smith and Wass 1990). In contrast, a similar operation on a high clay content, moderately well-drained sandy loam caused marked growth reduction in planted trees. Soil compaction on this latter soil probably reduced root growth, but was also accompanied by reduced infiltration rates and temporary ponding of snow meltwater. At 8 years, Douglas-fir close to the sites of the temporary ponds averaged 65% less volume and lodgepole pine 33% less volume than trees of the same species growing at a greater distance from the ponds.

Trends in growth over the first 8 years in our two oldest stumping plantations underline the danger of making early conclusions on growth effects. In one case, lodgepole pine appeared to have benefited from the disturbance when examined at 5 years, but no differences could be detected at 8 years. In addition, the growth

[4] Thompson, S.R. 1990. Growth of juvenile lodgepole pine on skidroads in the MSa and ESSFa biogeoclimatic subzones of southeastern B.C. (Preliminary results). Frontline Forest Research, Nelson, B.C. 7 p. Unpublished report.

of the pine on disturbed soil, compared to that on undisturbed soil, was on a steep decline at 8 years. On another site, growth of western larch on disturbed soil started slowly, but by 8 years was greater than that in the undisturbed soil.

As a further note on species differences, in our four plantations with side-by-side comparisons of lodgepole pine and Douglas-fir, average reductions in height growth were 9 and 14%, respectively, when these species were growing on disturbed soil. However, our plantations studies also lend support to the retrospective studies of Thompson[5] in which the growth of lodgepole pine was shown to be adversely affected by calcareous substrates. On skidroads built in moderately fine-textured, calcareous soils, height-growth reductions of up to 32% occurred on the inner surface 5 years after planting. So, while lodgepole pine does cope with soil disturbance better than other species on many non-calcareous soils, it is not a panacea. Senyk (Senyk and Smith 1990) found drastic growth reduction for western hemlock on skidtrails on the coast after 1 year. If this trend continues in later years, hemlock would have to be considered extremely sensitive to soil disturbance.

Other soil disturbance plantations that are ongoing include two of the B.C. Forest Service developed by Bob Mitchell and Bill Carr near Lumby in the ICH Zone. These have had their 3rd-year measurements. The trials include a vegetation control treatment designed to reduce the confounding effects of unequal competition. Watt and Standish (1989) reported on 3rd-year survival and growth of Douglas-fir and lodgepole pine planted on a variously impacted ground-skidded site north of Williams Lake. Treatments included ripping and seeding with grass-legume mixes. In an overall comparison of operationally planted, side-by-side skidder and cable-yarded clearcuts, Rollerson (1989) reported 12–20% less height growth on the skidded portions 2 years after planting.

Many other trials, though not specifically designed to assess soil degradation, can provide valuable information on the subject. In the oldest stumped trial near Salmon Arm, Morrison *et al.* (1988) reported significantly greater height (20–23%) and diameter (8–10%) growth of Douglas-fir and lodgepole pine in the stumped portion than in the non-treated. They attributed this to reduced vegetative competition in the stumped portion. The many FRDA trials evaluating the effectiveness of mechanical site preparation might well provide useful data on soil disturbance and productivity where data collected on planting spots are adequate or could be assessed after the fact.

### Use of Productivity Data

Productivity impact data have been used to develop degradation sensitivity keys. Productivity data have also been used to estimate growth losses on a regional and provincial level (Utzig and Walmsley 1988). In this latter analysis, the average extent of degrading disturbance for ground skidding was estimated at 15–28% depending on slope and season of operation — a reasonable estimate for the period under study (1976–86). Growth reduction for the degraded soil was estimated at 50%. With data coming from some of the more recent studies outlined in this paper, the 50% estimate appears high. However, being placed at the high end of the range does compensate for vegetative competition inequalities and the possibility that trees on some severely degraded soils would not reach a merchantable size and thus would constitute a 100% loss. In the future, it should be possible to use productivity data from disturbed soil to adjust AAC's (up or down) on the basis of species, soil, climate, and degree of disturbance.

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[5] Ibid.

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# OFF-SITE IMPACTS OF TIMBER HARVEST AND SITE PREPARATION

D.A.A. Toews

Forest harvesting has the potential to affect streamflow quality and quantity at sites far removed from the site of the disturbance. The mechanisms by which the impacts of forest harvesting and silvicultural activities are conveyed downstream are often complex and poorly understood. Discussed here are the nature of off-site impacts, some characteristics of off-site impacts in the British Columbia interior, the results of several water quality/forest harvesting studies undertaken in the British Columbia interior, and a description of the sediment budgeting techniques and their utility to forest management.

Off-site impacts may include changes to the streamflow, to the temperature, and to the chemical, bacteriological, and sediment regimes of streams. Of these, the sediment impacts are the principal concern and will, therefore, be emphasized here. Sediment can be affected by two distinctive erosion processes: surface erosion and mass wasting. Surface erosion is the detachment of individual particles of soil, usually by flowing water; mass wasting is the downslope movement of soil under the force of gravity. A major consideration is the degree of connection between on-site soil detachment and the downstream water quality or fish habitat. If the detached material is not transported to a stream channel, it will not impact on water quality.

Streamflow hydrographs and the natural sediment regime are dominated by spring snowmelt in the interior of British Columbia (Church *et al.* 1989). Most erosion problems in the Interior occur during the spring snowmelt period when streamflows are peaking. Typically, about half the watershed is covered with snow, and access to the site is poor because of snowcover on the roads. Often, some combination of a rainstorm on the melting snowpack triggers the peak flows or soil saturation that causes most of the erosion. Most landslides in the Interior are associated with the spring snowmelt period (Toews 1991). Most surface erosion is also likely to occur during this time. High intensity rainstorms in the fall may cause problems too. Because the major annual erosion event is related to snowmelt or some combination of snowmelt and rain, guidelines based on rainfall intensity tend to have little applicability.

Few studies of how forest harvesting affects water quality have been done in the interior of British Columbia. Consequently, many of the guidelines and the scientific documentation is based on material from coastal British Columbia or the USA (see Rice *et al.* 1972; Megahan 1981; Everest *et al.* 1987). Studies that document suspended sediment in the interior of the province include:

1. Slim-Tumuch Study (Slaney *et al.* 1977; Brownlee *et al.* 1988);
2. Dennis Creek Study (Hetherington 1976); and
3. Matthew Creek Wildfire Study (Gluns and Toews 1989).

Of these studies, the Slim-Tumuch was the most ambitious in that it attempted to monitor the effects of a variety of upstream logging treatments on water quality in a stream below. The major impact was from a forest road that cut into and destabilized a lacustrine silt bank at a location near the mainstem stream (Brownlee *et al.* 1988). This road cut was the major sediment source associated with logging. The study is typical of many that have found that most of the impacts are associated with forest roads. The Dennis Creek study documented very small suspended sediment level changes one year after forest harvesting (Hetherington 1976). The Matthew Creek study examined the effects of a wildfire on a variety of water quality parameters, by comparing differences between downstream/upstream water quality in two burned and salvage-harvested watersheds and an unburned tributary. The results indicate no significant changes in the mean turbidity and non-filterable residue values after the wildfire (Gluns and Toews 1989). The water quality studies cited are sufficient to indicate that roads, rather than the harvesting activities themselves, are the major cause of sediment problems; that there is often sufficient flexibility to allow for a variety of alternative harvesting and silvicultural systems, provided they are executed with sufficient care; and that the transport of sediment particles from the site of the activity to sites below is highly complex and variable.

A recently developed technique called sediment budgeting and routing investigates the complexity of sediment movement from its upland source area to deposition areas downstream. Scientifically, this area of

investigation involves measuring sources, storage, fluxes and the ultimate deposition of sediment within drainage basins, and these determining their variation in time (Swanson *et al.* 1982). This approach is very expensive and time consuming, and may require assumptions that are difficult to verify.

Conceptually, however, this technique can be very useful for planning, rehabilitation, and impact analysis. If one undertakes a preliminary evaluation of sediment sources, storage, and deposition, one can more easily evaluate the impact of management activities and determine those that are significant. During planning, one can put more emphasis on those activities that impact on significant aquatic resources below. In these areas, a manager may have considerable flexibility on the type of forest harvesting or silvicultural treatment that is undertaken. Conversely, a road crossing or a landslide immediately above a water intake or spawning bed can be the major source of sediment to aquatic resources below, and can warrant significant expenditures on a small part of the watershed. The concept of sediment budgeting is particularly applicable to watershed rehabilitation, where one must prioritize the benefits of controlling sediment sources in a variety of locations within a watershed. The most value to society will be derived from controlling those watersheds that have the potential to cause the most damage. In cases where there is no transport mechanism to move detached soil to a stream below, there may be flexibility to use a variety of silvicultural site treatments or harvesting methods. On the other hand, there are a few areas where specialized road and bank stabilization techniques are required to protect the water resource. The identification and control of sediment sources is neither complicated nor expensive: it simply requires that operations be planned and undertaken, with water quality protection as a key objective.

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# SELECTIVE LOGGING WITH C-SERIES SKYLEAD YARDERS AND RELATED EQUIPMENT

William L. Varner

Little selective logging has been done in the interior of British Columbia using a cable logging system on steep slopes and sensitive environmental areas.

In May 1987, a local cable logging contractor, Critical Site Logging Inc. from Vernon, B.C., worked on an experimental logging site near Falkland, B.C.

The British Columbia Ministry of Forests, Vernon Office, sponsored this experimental operation (total volume removed was 522 $m^3$). The project was supervised by Mr. Rick Smith, Resource Officer of Timber, and Mr. Jim Smith, Small Business Forester.

The yarder was a Skylead M35, mounted on a skidder, and used a skyline system with a hydraulic self-clamping carriage. The yarding was done uphill.

A yarding corridor was cut and then trees were felled to smaller, angled side trails. Logs were pulled to the main yarding road and then up to the yarder. A skidder moved the trees from the yarder to a common landing for bucking, sorting and loading.

The average yarding road width was 6 m; the maximum road length was 180 m; the average road length was 145 m; and the average road spacing was 45 m.

Critical Site Logging later purchased this timber sale in December 1987, after the experimental project was evaluated. They completed this successful selective cable harvest project with a minimum level of damage to residual timber, soil resources, wildlife and aesthetic values.

This was Critical Site Logging's first selective logging contract, other than the experimental project. I am sure that if anyone would like more information on this silviculture project, Jim Smith or Rick Smith would provide it. Their address is:

B.C. Ministry of Forests
2501 - 14th Avenue
Vernon, B.C.
V1T 8Z1

The public, resource managers and logging contractors are concerned about the protection of timber and non-timber resource values of our forests, such as water reserves, recreation, wildlife, fisheries and range land. Planning timber harvesting systems is the first and most important consideration to minimize logging costs.

Because harvesting in highly sensitive forest areas is costly, forestry planners should evaluate, at the planning stage, which type of cable system would be the most economical for the size of wood and the terrain. Factors to consider include:

- the road systems that are in place;
- the cost of new roads, if required;
- the new roads' compatibility with the overall management plan;
- whether harvesting equipment be used near streams or rivers;
- whether landing areas are available for delimbing, bucking, sorting and loading; and
- whether the overall plan includes reforestation costs.

No matter what type of cable system is used, all cable yarders depend on guylines and anchors to stabilize them as the tension builds in their working lines. Therefore, forestry planners will also have to consider:

- what site anchor systems are available;
- whether the size of the yarder, lines carriage and rigging will be supported by the local stumps, or whether it will be necessary to use machines to support the cable system;
- what the additional costs and environmental impact will be of extra equipment required for trailspar and guyline support anchor systems if they are necessary; and
- whether the harvesting method will provide for safe working conditions.

In the engineering and development of Skylead Logging Equipment we have balanced our yarder, rigging and carriage to harvest medium and small wood over an average distance of 250 m, and can add the option of intermediate skyline supports, if required. This allows us to harvest a total payload throughout the yarding operation, and gives us the ability to move, set up, and "in haul" wood with variable "line speeds." This lets us use our yarders to their full potential, with a minimum size guyline and anchor system.

The key work here is "balancing" the yarder equipment to the woodlot site, for a successful, economical logging operation. This is exactly what our new yarder has accomplished.

Cable logging contractors using the Skylead Yarders and Maki hydraulic, radio-controlled, self-clamping carriages, now have the ability to competitively supply mill owners with cable-harvested logs, both clearcut and selectively logged, at a cost they can afford. As well, the contractors can satisfy all local safety and forestry harvesting regulations.

Cable yarders, like all other equipment, are designed for specific jobs. No one yarder will successfully operate in all forest conditions. Therefore, contractors must determine which yarding equipment meets their own most common local forest planning requirements and harvesting regulations, before they purchase any new equipment.

The main objective of a cable logging contractor is to ensure that each crew member is trained to work as a part of a close-knit team. This ensures total maximum daily production of the yarder operation.

Skylead Yarders can be used for both clearcutting and selective logging operations. The C-Series yarders are equipped with a skyline, mainline and haulback winches, as well as a strawline and three guyline winches to facilitate downhill yarding.

Downhill yarding provides a means of yarding logs for extended distances, without access road construction, to ridge tops. In some cases, it eliminates the need for mid-slope roads. The planning, design and the operation of downhill skyline systems requires a higher level of effort than uphill skyline systems. The economic trade-off of downhill versus uphill is the difference between downhill yarding costs and access road construction costs.

Downhill yarding has a higher yarding cost because the:

- increased hand labour and time needed in rigging up and rigging down;
- reduced production rates as a result of lower payloads per turn; and
- reduced production rates as a result of increased hang-ups and slower in-haul speeds.

The best opportunities for downhill skyline selective yarding are on settings that can be designed to provide full log suspension, with the landings and yarding equipment located to ensure a safe operation.

Downhill selective logging also results in more damage to the residual stands, as logs have a tendency to roll and slide downhill as the load lines move the logs laterally towards the carriage.

Skylead has provided training programs for its new customers, when required, and I believe that it may be necessary to have vocational schools in British Columbia offering full operational cable logging courses some day soon. Skylead Logging Equipment Corp. would be interested in working with any group which feels that cable logging should be included in our province's educational system.

When harvest resource managers work together with cable yarder contractors, and both have a true understanding of each other's requirements, this overall co-operation will increase yarding production and lower the cost of the cable-harvested wood.

# SOIL DISTURBANCE GUIDELINES: PRODUCTIVITY AND ADMINISTRATIVE IMPLICATIONS

Dave Jewesson

I represent Northwood Pulp and Timber Ltd. of Prince George. Northwood is an integrated forest resource company producing approximately 1.5 million board foot measure (fbm) of dimension lumber, 2 million $ft^2$ of ⅛-inch veneer, and about 1500 tonnes of pulp each day.

To sustain this production, Northwood must harvest approximately 1.6 million $m^3$ of wood each year. Most of this wood is harvested by conventional line skidders, but a growing percentage of it is now being harvested by cable systems.

Northwood has been experimenting with alternative logging systems for a number of years. One reason is that part of Northwood's quota holdings rest on slopes that are not accessible by conventional logging methods. A more recent reason is the Ministry of Forests' growing concern over site disturbance activities and the possible impact on subsequent regeneration performance. Cable logging appears to be one of the options for addressing this concern.

The history of cable logging in the interior of British Columbia is rather grim. Lack of skilled labour for both the planning and the operating phases have contributed to poor logging performance in the past. Equipment used for cable logging in the Interior has largely consisted of machines brought here from the Coast. For the most part these have been large towers.

The smaller piece size and the lower volume per hectare characteristic of interior stands, however, do not support the use of large towers at an economical cost. On the Coast, the tower has been largely supplemented by the grapple yarder.

The grapple yarder yards faster and needs fewer men to run it. However, until recently, the grapple yarder developed on the Coast was too heavy and still too slow for logging in the Interior. Since the fibre supply on the Coast has been changing from large old-growth timber to smaller old- and second-growth timber, smaller grapple yarders have been developed to operate in smaller wood — and that's where the connection is being made to the Interior.

The technology now exists to log in stands with smaller timber. The grapple yarders being developed today are faster, lighter, and mobile enough to quickly cover those areas inhabited by low volume stands characteristic of the Interior. Since fewer men are required to operate this system, the importance of a skilled labour force has not changed. It has, however, become less of a concern than it was for the operation of a large tower.

Northwood has recognized the importance of block design to cable logging and is addressing the matter. The most important factors in ensuring the successful implementation of grapple yarders or any other cable system in the Interior, will be the co-operation that can be achieved between the Ministry of Forests and industry.

# KMC AND ITS APPLICATION TO LOGGING AND SILVICULTURE ACTIVITIES ON SENSITIVE SITES

Jim Edgar

## Introduction

What makes the Kootenay Manufacturing Company (KMC) High Speed Steel Track (HSST) log skidder different from other log skidders? What does this uniqueness mean to those whose job it is to plan harvesting on sensitive or steep terrain?

## Background: The Transition from FMC to KMC

In 1970, Food Manufacturing Company (FMC) launched a full scale program to design experimental HSST logging vehicles. By the end of the 1970's, components had been changed so that the machine would survive the harsh environment of log skidding. When FMC decided to divest its interest in the manufacture of Woodlands Equipment in 1988, Kootenay Tractor (KOOTRAC) purchased the skidder manufacturing business. A new division of KOOTRAC, Kootenay Manufacturing Company, was formed to build log skidders in Western Canada. Today several hundred HSST machines are working in logging operations throughout the world. There are about 100 machines in British Columbia.

## The Distinguishing Features of the KMC

### "Live," high speed steel track

The track is made up of 22-inch wide steel pads which are connected with rubber bushings for flexibility. The track is driven from the front and so it is laid on the ground rather than being pulled.

### Torsion bar sprung suspension

Five dual roadwheels and road arms support the machine on each side. These are sprung on 10 torsion bars which run through the centre of the machine and act as springs, giving 10 individual points of suspension which:

- absorb heavy shock loads to the machine; and
- absorb some of the shock loads the machine would otherwise transmit to the ground.

The combined features of live track and torsion bar suspension result in a machine whose track will mold to the uneven surface of the ground. There is more to low ground pressure than simply machine weight divided by track or tire area.

### Balanced weight distribution

Heavy powertrain components are located forward on the KMC, helping to balance the payload weight on the rear of the machine. The machine is equipped with a hydraulically extendable logging arch. Rather than being hung off the end of the machine, the load on the KMC actually becomes a part of its tractive effort.

## General Features of Logging Equipment Design

Whether we are describing a ground-based skidding system or a cable logging system, all machinery affects the ground on which it works in several ways:

- **Ground pressure**
  At shipping weight, the ground pressure of the KMC is 6.17 psi. In contrast, rubber tired skidders have a ground pressure of about 3 times that figure when equipped with standard width tires.

- **Number of suspension points/flexibility of suspension**
  Conventional skidding machines have three or four points of suspension. In contrast, the HSST skidder has 10 suspension points.

- **Vehicle weight distribution**
  Loaded weight distribution on the tracked skidder is about 60% rear and 40% front compared to rubber tired skidders and crawlers which are both about 80% rear heavy with a load in train.

- **Fluidity of the transmission of drive torque**
  Because of the rigid transmission of mechanical power, deep ruts are formed when high torque peaks are transmitted to the ground. When one wheel of a rubber-tired machine rides up over an obstacle, the opposite wheel receives a torque peak.

- **Steering mechanism**
  To turn a crawler tractor, a steering clutch is disconnected, disengaging track drive, and a brake is applied to the track, giving a very short turning radius but a large displacement of material. The KMC has a controlled planetary type differential steering system which transfers torque from one side of the machine to the other. The advantage is reduced soil disturbance.

- **Physical size of the vehicle**
  The 2000 Series KMC is 6 feet and 7 inches wide. The FT180 is narrower yet. The wider the vehicle, the wider the skidroads need to be to accommodate it.

**Machine Design and Site Degradation**

No one skidding machine can avoid all site degradation problems. However, if it is applied properly, the HSST skidder causes less site damage than some conventional ground-based skidding machines. It can limit compaction, soil displacement, and surface erosion as follows:

- **Compaction**
  Compaction is an increase in soil density caused by the rearrangement of soil particles in response to applied external forces. The low ground pressure of the KMC yields a reduced external force, though low ground pressure is not enough in itself to prevent compaction. The unique suspension system of the KMC translates low ground pressure into more even ground pressure.

- **Soil displacement**
  Displacement is reduced by the differential type of steering system used in the KMC. Additionally, the moveable arch lifts the log butts off the ground so that they are carried on the rear deck of the machine. This eliminates displacement from "butt dozing."

- **Surface erosion**
  The erosion hazard stays low so long as protective vegetation and surface organic layers remain intact. The tracked skidder can work without skidroads, even on fairly steep terrain, leaving the protective vegetation and surface layers intact.

**Conclusion**

No machine or logging system has zero impact. The objective is to keep impacts to a minimum. Because of the more evenly distributed low ground pressure achieved by its unique track and suspension system, the KMC offers an attractive machinery option for logging steep and sensitive areas.

# CUSTOM SKIDDERS: CATERPILLAR'S RESPONSE TO THE SKIDDING DEMANDS OF THE '90s

Mark Vander Griend

The new 90 horsepower D4H and 120 horsepower D5H Custom Skidders manufactured by Caterpillar are a direct response to today's logging requirements. These skidders are designed to minimize compaction, and minimize rutting and disturbance of the forest floor, while providing a favourable soil climate for regeneration.

New equipment, to meet changes in the marketplace, does not happen overnight. Its needs must be identified, the machine characteristics that affect these needs analysed, and vehicles designed to meet the needs.

Finning and Caterpillar have been involved in the British Columbia forest industry for more than 50 years. In that time, we have responded to the changes that are required and then helped the industry develop new productive equipment. Our inputs come from our customers, FERIC, the B.C. Forest Service, and other industry consultants.

In the evolution of the custom skidder, studies were done on the forest floor. Interaction between a machine and the forest floor was analysed. We looked at ground pressure under all types of known skidding vehicles. This information was very useful in helping us select the best characteristics for the new custom skidders. To meet the tight ground disturbance control requirements now in place, it became apparent that this vehicle would need:

- good load carrying capacity, especially with a grapple;
- favourable flotation and low ground disturbance capabilities;
- a productive dozing blade;
- a reasonable price; and
- good durability.

The next step was to look at these characteristics and see how we could engineer such a vehicle.

## Analysing the Need

Decreasing the ground pressure of a vehicle will not automatically give better flotation and reduce compaction and site disturbance.

Static ground pressure, or the specification you read on a specification sheet, is not the maximum ground pressure the unit is capable of exerting.

Dynamic ground pressure is determined by the amount of log pull and the location of the log pull of the loaded vehicle. The custom skidder overcomes this dynamic ground pressure by balancing the centre of gravity over its undercarriage. The relocation of the track frames has overcome this problem of dynamic ground pressure by placing the weight far forward over the standard conventional frame location.

## Responding to the Need

### Roller frame location

Determining the best roller frame location was not simple. It required balancing many variables such as: fore, aft and lateral stability; skidding performance; dozing performance; dynamic ground pressure; and ground clearance.

Ground clearance has always been a problem with conventional tractors. Couple this with cumbersome diagonal braces and you have a skidder that requires a blade trail to run on. The D4H has 22 inches and the D5H has 19 inches of ground clearance. This, together with a clean smooth belly, allows the skidder to minimize ground disturbance.

Undercarriage life on tracked skidders is critical. The forest floor is a tough environment and short track life has been the Achilles' heel of many tracked skidders.

The effect of wide shoes on chain life are well known and, until now, it has been a standard practice to use the narrowest shoe that will suffice. Wider shoes, however, greatly increase the capability of the tractor. They increase flotation and traction, and reduce compaction and ground pressure, widening the machine's operation range.

Three track shoe widths are being offered by Caterpillar. They are 18, 23, and 30 inches on the D4H line, giving 7.6 psi, 6.4 psi, and 5 psi, respectively. On the D5H line, shoes available are 20, 26, and 32 inches, giving 8.2 psi, 7.1 psi, and 5.9 psi, respectively.

| Model | 20" Shoe | 26" Quad | 32" Quad |
|---|---|---|---|
| D5H TSK Grapple | 8.8 psi | 7.5 psi | 6.4 psi |
| D5H TSK Line | 8.2 psi | 7.1 psi | 5.9 psi |
| **Model** | **18" Shoe** | **23" Quad** | **30" Quad** |
| D4H TSK Grapple | 8.2 psi | 6.9 psi | 5.4 psi |
| D4H TSKLine | 7.6 psi | 6.4 psi | 5 psi |

The wider shoes have incorporated Cat's new quad link configuration. This arrangement uses an extra single link strand at the outer edges of the shoe, thus reducing either vertical loads or snag loads that inflict twisting on the centre chain. A 5-fold increase in track life has been achieved in many field operations.

**Grapple arrangements**

The grapple version uses an arch pinned to the sub-frame, which mounts to the back of the tractor. We have worked with many of the attachment manufacturers to produce productive, two-piece and swinging grapples that do not unbalance the custom skidder, either loaded or unloaded.

The operation of these grapples under constant log pressure allows the operator to concentrate on the skidder's path over adverse conditions.

**Bulldozer blades**

Both the D4H and D5H come with a standard power angle tilt blade. They are the same rugged 96-inch and 125 x 54-inch dozer blades available on the standard tractor dozer. The blades are mounted close in to the tractor and the push arms are inside the roller frames. This not only improves blade control, but also reduces the overall width of the skidder to meet the narrow fores' specification now being enforced in British Columbia. The custom skidder can be fitted with a number of different bush piling and stumping blades.

**Other features**

Engine cooling is provided by Cat's exclusive folded core radiator. The modular cores deflect debris between gaps, allowing for excellent cooling in the harsh conditions this machine must work in. The electrical monitoring system (EMS) monitors the system and warns the operator if something is faulty.

Finning has branches throughout the province to handle any problems that might arise. Trained technical personnel in the parts and service department will keep the custom skidder fully operational.

### Verifying the response

The real proof in the pudding comes from field evaluations with loggers. Prototypes were tested by logging contractors in many different areas and the reception was enthusiastic everywhere. Finning has tested these units in the steep ground of the Kootenays, and in the heavy snow and steep, wet ground of the Mackenzie delta. These skidders have pushed and pulled on all slopes and grounds, outdoing all competitors. Furthermore, they have met or exceeded the strict ground disturbance requirements in each forest region.

### Summary

The new custom skidders from Caterpillar offer the logger a unique combination of an effective tracked skidder and a durable, capable bulldozer. They have evolved from our recognition of marketplace needs; our analysis of the characteristics that address those needs; and our use of this information to respond with appropriate vehicle arrangements. The custom skidders are an important addition to the broadening line of logging equipment from the Caterpillar Timber Team.

## PUBLIC PERCEPTIONS AND EXPECTATIONS

Warren Mitchell

The public has some very clear perceptions about forests, forestry, and the management of the resource. These perceptions do not necessarily reflect a forester's reality, but that does not matter, for when it comes to public opinion, perceptions are reality.

Yet all of the realities are only perceptions. Many people perceive the forest in a special, spiritual manner that may be something other than reality. And some people's negative view of forest management as being destructive may sometimes be other than reality.

I am often asked to talk about certain aspects of forest management practice in relation to the public. Sometimes the topic is herbicides, sometimes clearcutting, or like today, it's soil disturbance and site degradation. Yet, no matter how you attempt to categorize it, I believe that the only real issue in the public's view is the totality of forest management practices. No one aspect stands alone. Each contributes to the whole and the whole is often perceived as unacceptable.

A controlled broadcast burn is not necessarily viewed any differently than a wildfire because the public does not perceive the difference. They do not necessarily buy into the forester's argument that broadcast burning is a reasonable and correct prescription that will allow a forest site to be regenerated quickly and economically. Both are seen as unacceptable environmental degradation.

Confronted directly, people will usually agree that harvesting timber is a good idea. And they often know someone who knows someone who's cousin once made money from a horse-logging show.

So, they know that horse logging is economically feasible, and they don't clearly perceive that maybe the living standard of our province might be reduced if we only horse logged. But they do believe that from an environmental standpoint this must be a reasonable option.

The perceived disaster in the forest must therefore be due to the inability of foresters to see beyond present practices and effectively manage the public resource according to the public's wishes. In fact, I would suggest that many people think that large-scale mechanization in forestry, and the resultant site disturbance that can follow, are simply the unfortunate result of a mistaken land and forest ethic. We often underline their point by taking positions that are contrary to the public's objectives for the resource, or by prescribing or implementing practices that, unintentionally, lead to a perceived degradation of the resource.

This quote from *Our Common Future* captures the concerns of the public well: "How do we find the right balance of exploitation with preservation? And, perhaps more importantly, how do we ensure that forest management practices are not seen, or perceived, to be damaging to the environment and the resource?"

The public concern about forestry can be summed up by the fad for "New Forestry" which is sweeping the province. I am confronted with it frequently. People want a "kinder and gentler forestry." And they want to believe that the ecological values are at least being accommodated. But they would rather that ecological values become preferentially considered and direct forest management practices be secondary to them.

There is a great deal of talk these days about silvicultural systems, usually in the context of more selection harvesting and less, **MUCH LESS**, clearcutting. But these concepts are not necessarily well understood by the public, and unfortunately often not by foresters. We therefore end up with differences in perceptions and no common ground on which to find solutions.

The public perception is that when a conflict arises there is likely to be only one solution, because they perceive the power of the forest industry to be overwhelming in relation to the power of the forest dweller or the concerned environmentalist. The Carmanah decision will be seen this way by some of the public. And, unfortunately, no matter how much we protest or deny it, this is still the public's perception of its forest managers. I'm going to present some information from an Environics poll that was taken across Canada in 1989. Many of you will have seen this before, but it is well worth a second look.

What does the public think is the most important consideration in forest land use decisions? Almost two-thirds of the respondents considered potential environmental impacts as the most important consideration. This is far and away the number one concern of the majority of people today, easily outranking even a concern for the economic value of the resource.

And what is the greatest threat to our forests? Overcutting and mismanagement are perceived to be as much of a threat as acid rain and pollution. Thirty-one percent of the respondents saw our present forest management practices as the greatest threat to the forest. This should be very disturbing news to any practicing forester today.

And how much responsibility for damage to the forest falls to the forest industry? Over one-third of the respondents consider that the industry damage to the forest is "a great deal." A further 45% consider that the industry does "some" damage.

Clearly, the public's perception of the job we are doing in the forest is at odds with our own. But perhaps the most interesting, and disturbing, perception is the one about government regulation. Apparently the public believes that there is not enough regulation of the industry. I believe that we will continue to see much more pressure on government and industry to tighten up our forest management practices so that they come more into line with the perceptions of the public owners. This tightening will be through increasing government regulations — a move we are already seeing today.

Finally, I would like to talk about the credibility of forest managers. I consider this appropriate since a public demand for more regulation is really an indictment of forest managers.

If, as is commonly perceived, many politicians have no credibility, forest industry executives don't have much either. In fact, when it comes to sources of information on forestry issues, the public perception is that environmental wilderness groups have the most credibility, even though you and I know that they don't have any at all.

The surprising statistic is that, given the current climate of public opinion, as many as 36% of the respondents felt that professional foresters, as a group, are a credible source of information.

I think that we, as foresters, should preserve our credibility as carefully as possible. All of our prescriptions should be undertaken with enough care and thought to ensure that we do not erode our good name further. All of our forest practices should be implemented cautiously as well, so that our results do not degrade the resource. Too often we have been guilty of talking about how well our forests are managed but then providing our critics with examples of damage and degradation that are unacceptable. If we wish to instill the public with a sense of awe about the management of the forest resource, and if we wish to continue to be the managers of that resource, then we must stop tripping on the stairs.

And remember, in the public realm **PERCEPTION IS REALITY**.

# SITE DEGRADATION: POLICY

M.H. Wyeth, R.P.F.

I appreciate the opportunity to be able to speak to this conference on such an important topic. Every day there are questions being raised by the public about how the forest industry treats the land base.

I shall approach the subject under the following topics:

- Why control site degradation?
- Purpose for policy
- History
- Current status
- The future
- Summary

## Why Control Site Degradation?

I believe there are three main reasons why site degradation must be controlled.

The first is simply **ethics: We care about the land**. This must be the starting point for land managers. This has not always been the case in British Columbia, but I believe it is now becoming an ethic, and one the public holds. If we care about the land we will not perform practices that are inimical to its long-term value.

The second is **productivity**. The foundation for forest plant life is the soil. If that is destroyed, the potential for growing forests is lost. So, for entirely selfish reasons, the forest industry needs to protect the soil because it is the underpinning for future wood supply.

The third reason is to protect all the **other resources**. The other resources either depend on the vegetation which lives on the soil, or can be damaged if the soil lands in the wrong place. Here I am thinking about siltation in streams and rivers. Not least, there is the issue of visual impact: people simply do not like to see it.

## What Purpose Can Policy Serve?

Despite many people's opinions, policy can in fact be useful, not just bureaucratic. Its purpose is to direct actions and effect change. It is a way for those in charge of an organization to describe the way decisions are to be made.

One of the features of policy is that it is not bound by perfect information. There has been a wealth of research in the area of site degradation, but not all the answers are in. Does that mean we should not form policies to control site degradation? No! Policy can be formed from the best available information and then tuned when finer information arrives.

The majority of actions that degrade soil are associated with transport. Obviously this is a necessary stage when the land use choice is the production of timber. The principles of total chance planning can help to optimize the layout of roads for the long run. Each segment of the transport network should be built to the standard that is necessary for its purpose. Any excess, in effect, throws away the land; it converts productive land to unproductive without a needed use.

Policy can also be the link between legislation and guidelines. The silviculture regulation requires limits on site degradation, yet the guidelines propose standards for site disturbance. This is based on the policy statement that **site degradation** is considered to be **unacceptable site disturbance**. There are many times when site disturbance is a recommended treatment for a site, so this link allows a line to be drawn between what is desirable and what is not.

## History

Under this topic it is tempting to ask "Does anything really ever change?" Change has been slow. Some of the other speakers have recorded events of the past, but I would like to note some of the significant ones from my point of view.

In 1974, Nelson started its Steep Slope Committee, and in 1976 the first Ground Skidding Handbook was published (FERIC 1976). Review of this will show how much we have changed our views.

In the early 1980's an Association of British Columbia Professional Foresters meeting was pivotal in recommending the need for a policy, which was finalized in 1984 (B.C. Ministry of Forests 1984). The silviculture regulation[1] was deposited in April 1989. Section 2(2) (f) requires that the maximum degradation be set for a proposed harvesting area. In 1989, the guidelines to help set the limits for this requirement were distributed (B.C. Ministry of Forests 1989).

## Current Status

The preceding section outlined the history which leads directly to the current state of affairs. For each cutblock, a maximum limit of site degradation must be set in the pre-harvest silviculture prescription. The limit set should be within the guidelines. What should be recognized is that those guidelines set maxima: where current practices do better, the guidelines must not be used to raise the limit. The purpose of the guidelines is to improve performance.

As a point of clarification, haul roads that serve a number of cutblocks should not be "charged" against one particular block. All those actions that serve just one block should be "charged" against it. This should allow the optimum mix of roads, landings and trails to be used.

Although there is a regulation setting the maximum amount of degradation, and guidelines to suggest limits, there are currently no penalties in place should an operator, major licence holder or small business — exceed the limit.

## The Future

In this section I would like to discuss some of the issues that I believe should be dealt with next.

First there is the need to establish **penalties**. It is not appropriate to depend solely on goodwill. The nature of the penalties will have a significant impact on their effectiveness. An old adage should guide us: the punishment must fit the crime. This means that the penalty must vary with the impact of the degradation, and must be of an appropriate severity. The penalty should have a significant impact on a licensee, but not bankrupt that licensee for a minor infringement.

Most problems seem to occur, not from willfulness, but rather from the taking of shortcuts. Why are such shortcuts taken? Usually to save money. So an effective method that I envisage would be to make the penalty equal to twice the cost difference compared to doing the job right. This should correct the balance as licensees will realize it will be less costly to control site degradation properly the first time.

A major shortfall in protecting the soil has been the lack of **training**. Training has costs, so it is not surprising there is little investment when no costs can be saved as a result of the training. By making poor performance cost more, the equation is balanced so that training becomes cost effective.

Having dealt with performance correction, our next goal will be to improve the expectations for performance. The first part of this should be to set targets in addition to the maxima. Just as we are moving toward judging performance in stocking standards in relation to the achievement of targets, not just minima, performance rating in protecting the soil should be in the light of the best (i.e., targets).

The impact of this could be really dramatic. Each 1% reduction in average soil degradation can save roughly 20 000 ha per decade. Thus, a cumulative reduction of 1% per decade could lead to saving 120 000 ha by the year 2020, (20 000 the 1st decade, 40 000 ha the 2nd and 60 000 ha the 3rd) compared to current practices. That is a very large area, but I believe achievable.

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[1] B.C. Reg. 147/88, Silviculture Regulation.

**Summary**

The aim of policy is to control the amount of losses from site degradation.

This paper contends that there are three main reasons for such control: to care for the land, to retain productivity, and to protect other resources. Policy is the vehicle to direct actions.

The history of this subject is far too long. Only in the more recent period has the semblance of control started. Currently this control is achieved through silviculture regulations and the guidelines. The Basic Silviculture — Reduction of Productivity Losses policy links the terms site degradation and disturbance.

In the future, the first issue to settle is that of adequate and fair penalties. Once these are in place, setting targets rather than just maxima, should lead to achieving the goal of steadily reducing the amount of precious land that is made unavailable for future production through site degradation.

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# PROCEDURES FOR IMPLEMENTATION OF SITE DISTURBANCE GUIDELINES

Dave Lawrie

To my knowledge, work on the development of a set of logging guidelines began as far back as 1981 with a memo from the then Chief forester, Bill Young. This memo stated that there was "a lack of progress in the development of environmentally acceptable logging systems for the harvesting of steep slopes in the Interior." It further noted that "the Ministry of Forests should identify the Branch with the responsibility to develop and monitor policies relative to logging systems [Engineering Branch]."

This was how I became involved in working on what we called at the time "Steep/Critical Slope Logging Guidelines."

Some policy statements resulted from these guidelines, and probably not much else. However, one concept that did evolve from them was that, for ease of administration, any attempt to monitor logging disturbance should be done on the basis of area measurement. This concept was not to imply that all disturbance generated during logging was good, bad or indifferent. Rather, it suggested that if the area of disturbance allowed was regulated on a site-specific basis, then the amount of disturbance that might be detrimental could be better controlled.

The concept of measurement of disturbance based on area is embodied in the Interim Harvesting Guidelines that we have in place today. These guidelines were prepared by a Technical Advisory Committee (TAC), made up of representatives from industry and the Forest Service and chaired by Alex Sinclair of FERIC.

The TAC reports to the Interior Forest Harvesting Council, to whom the Interim Forest Harvesting Guidelines were submitted. The interim guidelines were approved for application to the interior of British Columbia by the Ministry of Forests Executive on April 28, 1989.

Now I will give you some background that defines the authority under which these harvesting guidelines are issued.

In 1987, the *Forest Amendment Act* came into being. It required the holder of a major licence to prepare: a Pre-Harvest Silviculture Prescription — a PHSP which includes measures required by the regulation. The Silviculture Regulation requires that "major licence holders will prepare a **PRESCRIPTION** which will state the maximum proportion of the area that may have site productivity degraded by roads and landings." The Interim Harvesting Guidelines, therefore, outline the procedures by which the licensee can fulfill the requirements of the PHSP.

In a nutshell, the mechanics of the Interim Harvesting Guidelines require:

1. a site review to determine sensitivity rating;
2. a decision by the licensee on the area of disturbance required for logging (i.e., preparation of a logging plan);
3. a comparison of logging disturbance required, to that allowed by the site review rating; and
4. an adjustment to the logging plan, if required.

The area of definition for the application of the guidelines is generally the cutblock. Site sensitivity, however, may determine that smaller treatment units within cutblocks, or smaller cutblocks, should be defined.

For instance, an area that was originally designated as a cutblock may be divided by a creek, with steep ground on one side and a gradual slope on the other. The two portions of the cutblock should then be considered as separate treatment areas or possibly as two separate cutblocks.

A field review of each treatment unit is carried out by the licensee to determine slope, soil type, moisture, aspect, etc. — information required to determine the maximum area of construction disturbance that will be permitted on the specific treatment area or cutblock. ("Site Sensitivity Interpretations for Timber Harvesting to

Minimize Degraded Sites" by T. Lewis.) To determine this maximum allowable level of disturbance, the field data are applied to a site sensitivity rating system and the level is expressed as a percent of the total cutblock area.The licensee will next determine the area of site disturbance that he will create in logging the treatment area or cutblock. This area will include that required for the bladed construction of skidroads, backspar trails, landings, and unapproved haul roads, as well as for the running area needed for heavily used skidtrails.

The Interim Guidelines next call for the production of a harvesting plan on which the size of landings and the area to be covered by other disturbance will be shown and indicated as a percentage of the total cutblock area. The percentage of area disturbance required by the licensee (as indicated on the logging plan) can then be compared to that which will be permitted by the site sensitivity rating system, as shown on the PHSP. If the logging plan requires more area of disturbance than is permitted by the rating system, then the licensee must adjust the logging plan or perhaps select an alternative method of logging. Once the logging plan map is complete, it is submitted to the Ministry of Forests, along with the cutting permit application.

That is the essence of the interim guidelines. But keep in mind the term "interim." One of the conditions that was placed on the TAC by Wes Cheston's letter of April 1989 was that the Committee would carry out an initial review of the guidelines by the end of the first year.

To this end, a questionnaire has been sent to industry and Forest Service personnel. I would like to thank those of you here who took the time to fill out the questionnaire and returned it with your comments and suggestions. I can assure you that the Advisory Committee is in the process of reviewing the questionnaires and your input will be reflected in any update of the guidelines.

Judging by the responses we got, the Committee has some work to do to improve the format of the guidelines. To illustrate, I would like to mention a few of the comments we received:

1. **Old "Murphy's Law" again!**
   "Did not receive a copy of the guidelines." The original memo by the Assistant Deputy Minister was addressed to the Interior Forest Harvesting Council (IFHC) "for distribution." A further memo from the Director, Timber Harvesting Branch, was sent to all the Regional Managers with the request that "all employees and industry affected by these guidelines receive a copy."

2. **Poor readability; lack of flow.**
   This is something that the Committee will deal with, probably rewriting the guidelines in more of the "how to" form. I might mention that at present the Procedures Manual for the Timber Harvesting Branch is undergoing revision and the section on Soil Disturbance will be written in collaboration with Silviculture Branch, according to the "how to" format.

3. **"Disturbance" in the Guidelines versus "Degradation" in the Silviculture Regulations was of concern.**
   In the rewrite of the guidelines we will get around this problem by including the statement, "To clarify the wording and provide conditions for implementation of the 'Interim Harvesting Guidelines' the word 'degraded' in Section (2)(2)(f)(Prescription) of the Silviculture Regulation shall be interpreted to read 'disturbed'." Finally, to those of you who did fill out the questionnaire, the Committee made a mistake in not requesting a contact name for the person filling out the questionnaire, so if you do not receive a thank you follow-up, we thank you now and offer our apologies.

# DEVELOPING TIMBER HARVEST STRATEGIES TO MINIMIZE SOIL DISTURBANCE

Rick Smith

This paper briefly examines only one part of the strategy to minimize soil disturbance during the harvesting phase: logging methods. It is important that logging methods not be considered in isolation from the other important aspects of harvesting such as road construction, landing construction, road maintenance, deactivation, and rehabilitation.

Assuming that proper planning procedures have been followed, including "total chance planning," the key stage at which the logging method should be refined is the Pre-Harvest Silviculture Prescription (PHSP). There are many social, economic, silvicultural, and resource value concerns to be addressed in a PHSP, but I will focus only on the operational harvesting concerns at this time. One of the first procedures is to identify the ecosystem units, usually the "site series," and to combine them into suitable treatment units. However, it is important that soil and terrain variation also be examined at this stage. To do this, the area should be stratified and classified into "degradation sensitivity units" as described in Developing Timber Harvesting Prescriptions to Minimize Site Degradation - Interior Sites: (T. Lewis *et al.* 1989. B.C. Min. For. Victoria, B.C. LMH field guide insert).

Degradation sensitivity units assess the risk of four major site degrading processes that may result from harvesting: compaction, displacement, surface erosion, and mass wasting. Sensitivity to degradation is expressed as low to very high for each unit. There is a corresponding Ministry of Forests guideline for the maximum amount of disturbance acceptable for each sensitivity class.

The key step is **stratification**. Considerable variation of sensitivity may exist on a given site, and it is important that this variation be addressed. If an area is not stratified, the standards applied should be equivalent to the standard for the most sensitive conditions on the area.

For example, most of a cutblock may be flat, with a small stream traversing one corner of it. The flat area may be low sensitivity, but because of steep streambanks the remaining area may be high. Without stratification, the standard applied should be equivalent to the highest sensitivity; it is not acceptable to average the disturbance levels over the entire block. The consequence could be high disturbance levels on the creek banks, which may be compatible with the overall low sensitivity, but could lead to erosion or mass wasting into the stream, not to mention on-site degradation of the soil resource itself.

The Ministry of Forests guidelines (April 28, 1989) for disturbance associated with bladed skidroads, landings, backspar trails and heavily used skidtrails specify that the cumulative total should not exceed the following:

| | | |
|---|---|---|
| low sensitivity | - | 19% |
| moderate | - | 19% |
| high | - | 9% |
| very high | - | 4% |

Most sites in the Interior will fall in the low to moderate category, which provides a lot of flexibility for operators. It should be kept in mind that roads, fireguards, and site preparation are additional to the guidelines and that the cumulative total of potentially degrading disturbance on a site could be very high. The overall objective should be to minimize detrimental disturbance wherever possible. Managing to the maximum guidelines is **not** acceptable.

In addition to the provincial guidelines, there are additional guidelines for the Okanagan Timber Supply Area which restrict both the distance between skidroads and the depth of cut. Consistent with the strategy to minimize disturbance, the minimum distance between skidroads is restricted to 30 m. Even more important is the need to restrict the depth of cut on skidroads, because as the depth increases, the extent of and risk for displacement, mass wasting, compaction, and erosion also increase significantly. Consequently, depth of cut is restricted to a maximum of 0.6 m on slopes up to 50% and to a maximum of 0.25 m on slopes over 50%. The significant restriction on slopes over 50% is intended to encourage the use of alternate equipment or alternate harvesting methods such as the use of snow skid trails.

Assuming that rubber tired skidders in combination with hand felling or feller-bunching represent "conventional" logging equipment, it is safe to say that the guidelines for disturbance can easily be attained on most low to moderate sensitivity sites with conventional equipment. The key to success is educating machine operators to minimize disturbance. There are still many operators who think they are doing a good job by building extra skidroads and excessively wide, straight skidroads to make the skidder operator's job easier. As well, there is still the macho image that some operators try to express by pushing their way through anything and everything. This image is often reinforced in machine advertisements.

The use of pre-designated skidroads, laid out in advance, reduces disturbance and logging costs. It is an appropriate strategy for most ground skidding operations. The main areas where conventional equipment will get into trouble on low to moderate sensitivity sites are on slopes from 40 to 60% and on saturated medium- to fine-textured soils. On the steep slopes, conventional equipment operators will usually need to use steep gradient skidroads or compatible snow-to build skidroads, or else will need to obtain permission from the Workers' Compensation Board to "random skid" (without bladed skidroads), in order to meet the disturbance guidelines. On saturated soils, there are really only two options with conventional equipment: either avoid logging until the soils dry out, or harvest when the ground is frozen.

The other choice for steep slopes or saturated soils is to use alternative logging equipment that is also appropriate for harvesting on high and very high sensitivity sites. Low ground pressure flex-track skidders are often effective on fine-textured soil types and saturated soils. They also minimize disturbance on slopes up to 50% where the timber and the terrain permit random skidding without blade-constructed skidroads. Wide-tired skidders have also shown promise on similar sites, but both machines have not received much use in British Columbia, and flex-tracks have been plagued by a history of high operating costs and excessive down time.

Small crawlers, of the D-4 size and smaller, have received considerable use in the province and have proven to be dependable. They have also proven to be effective at reducing disturbance levels compared to conventional equipment, especially on moderately steep ground.

With proper skidroad design, small crawlers should have no problem in meeting the disturbance guidelines for low to moderate sensitivity sites on slopes up to 45%, and even up to 60% if the skidroads are constructed primarily out of snow. However, on high or very high sensitivity sites, small crawlers are not recommended for slopes over 45%. On one of the benchmark disturbance study areas in the Vernon Forest District in 1989, small crawlers (TD-8's) and medium rubber tired skidders (Cat 518's) were used on a medium sensitivity site. The crawlers were used on the steeper ground and the skidders on the remainder. The slopes averaged 35–45%, yet the disturbance level was 24%, considerably above the 19% guideline.

Horse logging can play an important part on sensitive sites that are not excessively steep and where the extremely narrow skidding surface, though possibly compacted, has a negligible impact on the site. Helicopters may also be important in the future for logging high value timber on almost any site where the turnaround time can be kept to less than 2 minutes.

Cable harvesting equipment, high lead or skyline, is effective for minimizing disturbance levels on most sites, provided the roads can be located on stable ground. In fact, cable harvesting may reduce the amount of road by combining uphill and downhill yarding. The cost of cable harvesting averages 50–100% higher than conventional harvesting, but cable machines have proven to be sufficiently versatile and dependable to warrant inclusion in any company's arsenal if they have any amount of steep ground in their operating area. In the benchmark disturbance study areas in the Vernon Forest District, the cable harvesting easily attained the guidelines even on high sensitivity sites.

Steep slopes in high visibility areas present a special challenge to loggers in British Columbia. Not only do many of the public oppose clearcutting in principle, but they take particular exception to large clearcuts and to excessive disturbance levels in high visibility zones. Consequently, many of these areas have been avoided and are being grossly under-utilized in comparison to their contribution to the annual allowable cut (AAC). Furthermore, if "Visual Quality Objectives" are to be attained by conventional methods, severe reductions in available timber are inevitable.

Guidelines restricting first pass logging in visually sensitive zones to 5–15%, with 25–35 year green-up periods before the next pass, are already being formulated. However, there is a method of harvesting these sites in a manner that is acceptable to society and still extracting up to 50% of the stand during the first pass. That method is skyline selection logging, and it has already been successfully employed in the Vernon Forest District on several sites.

Several different cable yarders are suitable for this type of logging. The key ingredients are a fairly mobile spar with skyline configuration, a clamping carriage, and a small enough line size to permit relatively easy lateral line pulling up to 30 m from the yarding road. Yarding roads need only be 5–6 m wide, and should be at least 45 m apart. Trees are normally felled at a 45° angle away from the yarding road and butt skidded. A slightly linear felling pattern is advantageous, but not essential, as there are several techniques by which the logs can be manipulated through the residual stand with remarkably little scarring damage.

In terms of versatility, dependability, and cost effectiveness, I believe that cable yarding systems show the most promise for minimizing harvest impact on sensitive sites. Although other alternative logging methods have a valid place on many sites in British Columbia, I believe that all except helicopters will have limited future application on slopes over 45%. Growing awareness of the on-site and off-site damage caused by detrimental disturbance can only be expected to result in more stringent standards in the future.

Water quality is emerging as one of the greatest public concerns associated with logging in British Columbia, and water quality is closely tied to site disturbance levels. Although the use of snow skidtrails can produce acceptable results with most ground skidding equipment on moderate slopes, the window for suitable snow conditions is too narrow to permit this technique to become a widespread production method. Even more importantly, adequate drainage control is difficult to establish in the winter. Water bars are difficult enough to establish in frozen ground, but even if they are, we cannot see everything under the snow. As a result, it is almost inevitable to find erosion during the first break-up following winter logging. This is no longer acceptable within community watersheds or near fish spawning habitat.

I believe we have the necessary equipment and expertise to respond to the challenge to reduce logging disturbance levels. As long as the motivation exists to continue making improvements, there should be no need to introduce restricting legislation as has happened in other countries.

# HARVESTING STRATEGIES TO MINIMIZE SOIL DISTURBANCE: AN INDUSTRIAL PERSPECTIVE

Bob Harrison

## Introduction

I think it is accurate to say that up until recently, the main concern of our harvesting operations was to produce logs at a reasonable cost. Our main emphasis was aimed at only the logging phase of our industrial operations. We didn't concern ourselves very much with good forest engineering and long-term development, nor did we really think a whole lot about post-harvesting activities such as site preparation, planting, and the general establishment of the next crop. We were only concerned about getting logs to the mill as cheaply as possible. Those other things were somebody else's problems.

Those past operating practices have been rightfully criticized and our operations today are being governed by a myriad of guidelines designed to lessen the impact of our logging operations on the forest environment. A recent guideline that was introduced to our operational activities is the "Soil Disturbance Ground Rules."

The title of my talk today is "Timber Harvest Strategies to Minimize Soil Disturbance: An Industrial Perspective."

At the risk of being repetitious, I'd like to spend a few minutes reviewing the main points of the Soil Disturbance Guidelines.

The interim soil disturbance ground rules for British Columbia were introduced in April 1989. The objective of the guidelines is simply to prevent unnecessary soil disturbance resulting from our harvesting activities. The ground rules apply to harvesting-related disturbance only. At this time they do not apply to silvicultural activities.

As a result of considerable study and analysis of slope, soil type, and soil moisture content, a soil sensitivity class has been developed. The maximum allowable level of soil disturbance is tied to the soil sensitivity class. The maximum allowable disturbance for the broad soil sensitivity ratings is: very high (4%), high (9%), moderate (19%) and low (19%). I must emphasize, however, that these are the maximum allowable disturbance levels and, where it is practical, we should try not to exceed them.

Soil disturbance is measured on landings (the widened portion of haul roads beyond the standard width), backspar trails, bladed skidroads, and heavily used skidtrails. Disturbance measurements are taken from the top of the cutback to the toe of the fill. **Not** measured as soil disturbance at this time are approved haul roads and fireguards. With these guidelines in mind, let's talk about ways that we can conduct our logging to meet or exceed the soil disturbance ground rules. The four areas where we can develop harvesting strategies to reduce soil disturbance are forest engineering, logging, road construction, and post-harvest maintenance, including roads.

## Forest Engineering and Planning

High quality forest engineering is the catalyst to achieving acceptable soil disturbance levels. It is imperative that forest engineering be approached from the "total chance" planning concept. We must be willing to provide our field engineers with the best available equipment. Up-to-date aerial photography, large scale planimetric contour maps, and good field transportation are the minimum that we can provide our crews with. In addition, we need to ensure that our people are well trained in not only basic engineering procedures but also good planning and development concepts including the needs of other resource users. We must provide opportunities for our forest engineers and planners to learn about harvesting and road construction equipment, how it is used, and the capability of that equipment as it is used with various harvesting systems.

Incomplete or piece-meal planning and development is no longer good enough for the complex operating plans that are required for today's operations. Entire drainages must be engineered and planned with the total chance concept in mind. Our plans must consider the entire road system needed for the total development of

the drainage, the cutting patterns and sequence of harvesting, the protection of other resource values, and the logging systems that will be required to harvest the timber with the least impact on the particular drainage.

The engineer must establish good communications at the outset with the company and contract logging personnel, and with the various government agencies that will be involved with the operation. Upon completion of the plan, the planner must continue to communicate with the loggers who will be responsible for the execution of the plan. The plan must always be flexible to allow for change in the event of unforeseen conditions. Good engineering and planning are not a luxury for today's complex development requirements. Clearly, total chance planning will provide for cost-effective and efficient logging operations that will have the least impact on the forest site.

**The Harvesting Phase**

The second and certainly most critical area where strategies must be developed to reduce soil disturbance is the harvesting phase. The logging operation is merely the execution of the plan. That is why it is critical that the planner and the logger work together in both the planning and plan execution phases. The role of the forest engineer in the planning and development of the harvest areas is repeated during the execution of the plan by the logging supervisor. The logging supervisor is the key to ensuring that the actual logging activities are carried out in accordance with the plan. He is the leader of the band and he must be totally familiar with all the various rules and regulations and company policy. He must also be very knowledgeable about equipment and harvest systems.

I believe that logging supervision is the single most important key to achieving low impact harvesting, but unfortunately it is one of the areas that is neglected the most in our Interior logging practices. Clearly, we must be prepared to spend a higher percentage of our logging dollars on supervision. The payoff will be realized in lower logging costs and in harvesting operations that have the least impact on forest soils, water quality, and other resources.

Before logging begins, the supervisor must become totally familiar with the ground and timber conditions and areas of the block that may require special operating consideration. With his knowledge of equipment and harvest systems and with the forest engineer's development plan, the supervisor must carefully plan the location of landings, skidtrails, stub spurs, backspur roads, and fireguards. He must develop a falling and skidding plan and, of course, a post-harvest maintenance plan. All this should be done before the actual logging activities start.

Upon completion of the preliminary logging operations plan, the supervisor must then communicate the plan to the people that will be involved with the operation of the equipment. As elementary as it may seem, many of our operating problems are a result of poor or incomplete communications with the people who are actually doing the work. The supervisor must be prepared to spend as much time as required, on the site, to ensure that his operations plan is being followed correctly. During the operation phase, the major role of the supervisor is to communicate and coach the equipment operators frequently.

Like the development plan, the logging plan must not be written in stone. If plan changes are required during the operations, our plans must be flexible enough to allow us to make those changes.

The selection of logging systems and machine type is an important factor in reducing the impact of harvesting on the forest site. Like supervision, we do not spend enough time or do a good enough job on selecting the right tool for the job. I believe that if the right machine or machine system is selected, we can comply with the soil disturbance guidelines and still maintain acceptable costs.

**Road Construction**

The next area that requires some discussion from a soil disturbance perspective is road construction. Like harvesting, road construction requires careful planning that considers the type of equipment to be used and the timing of construction to minimize soil disturbance. Since my time is limited, I will not talk about engineering considerations but, rather, about construction systems that should be considered to lessen the impact on soils.

**Post-Harvest Maintenance**

An area that I feel is neglected far too often in our harvesting activities is what I call post-harvest maintenance. We must do this to reduce the potential for water-caused surface erosion. I believe surface erosion can be controlled to acceptable levels if good maintenance practices are used.

**How Do Our Operations Stack Up?**

On a scale of 1 to 10 (10 being the best), I would rate our interior logging practices at 6 for reducing soil disturbance. I think we can get to 9 on the scale quite easily by simply practising a higher standard of total chance planning and by improving our supervision and applying the right harvest system to the terrain and timber types.

We must be careful not to set very low disturbance levels for our logging practices and then to relax those disturbance levels for our post-harvest silvicultural activities. The bottom line soil disturbance level that we are willing to accept must be a combination of both harvest and post-harvest activities.

The Valuation Branch of the Ministry of Forests must be prepared to allow realistic costs for the harvest systems, which will be required to meet the desired soil disturbance levels.

I believe a major concern of industry is the method by which guidelines are developed and administered. We find that far too often guidelines are developed without much meaningful consultation or co-operation with the industrial sector. Frequently, it appears to industry that guidelines are developed by government simply to administer compliance with a particular practice, rather than to develop a co-operative practical, common sense approach to solving an operational problem. If we truly want the soil disturbance guidelines to function as they were designed to, then we must work together and be prepared to make positive changes to the guidelines as new information becomes available.

# IMPLICATIONS OF SITE DISTURBANCE GUIDELINES ON TOTAL CHANCE PLANNING

John Peterson

Good morning. It's a pleasure to talk to you today about the implications of the interim soil disturbance guidelines on total chance planning.

The soil disturbance guidelines complement the total chance planning concept. The objective of the guidelines is to reduce soil disturbance during harvesting, and soil disturbance levels can be reduced by total chance planning. They are a natural fit because the guidelines encourage better planning; and better planning is a direct outcome of total chance planning.

**What Is Total Chance Planning?**

To quote from FERIC's Handbook No. 4, *Timber Development Planning for the British Columbia Interior: The Total Chance Concept*, "Holders of major Crown timber rights must prepare Resource Development plans under MOF authorization and according to co-ordinated resource management guidelines set at the local level. The development area may be a single mountain drainage or an arbitrarily defined area in rolling terrain. Typically it will require several years to develop, harvest and restock, and will contain a mixture of easy and difficult operating chances."

A development area requires "total chance" rather than piece-meal planning. The total chance concept is the name given to early planning over an entire development area for the best overall realization of all objectives identified by broader planning. As one Interior forest company states, "all of the timber in a given drainage must be assessed for development before it is divided into smaller logging units related to logging or road-building systems." The Ministry of Forests encourages total chance planning by licensees as the best way to avoid "short-term gain and long-term pain."

Handbook No. 4 deals mainly with timber development planning. But, as you know, we can no longer plan for just timber harvesting alone. Today's manager requires a systematic and practical approach that will allow the management of all resource values and, at the same time, provide for an economic timber supply.

Foresters must understand the changing attitude of society towards forest management and provide constructive leadership in integrated forest management. Society today wants the forest to provide a sustained supply of both timber and non-timber resources. One hundred years ago, forests in British Columbia were viewed as obstacles to development of agriculture, roads, railways, and settlements. Society gradually realized the value of timber, and forest management then focused on fire protection and replenishing the timber supply through silviculture. Today, we are at the point where forest management must include a full range of timber and non-timber resources.

In 1989, FERIC was approached by both the Forest Service and the forest industry, and asked to put on seminars that would deal with this complex issue. The outcome has been a series of twelve 4-day seminars, being conducted throughout the province, entitled "Integrated Resource Planning." These seminars take the total chance concept for timber development and develop it further to incorporate the management of all resources.

The key to good planning lies in "long-term" planning. By this I don't mean just 5- and 10-year plans. What I'm talking about is taking a specific geographic area, such as a watershed, and planning activities within it for at least one full rotation, and in some cases, longer. Not only plan harvesting operations, but also plan for the management of all resources. In addition to harvestable timber, these resources include such categories as: buffer zones, old-growth retention, caves, recreation, fish, trap lines, forage, water quality, landscape, wildlife, in addition to many more. The final decision as to which resource is more important than the others will probably have to be made as a consensus statement. This will require all interested parties to work together, including the industry, government agencies, and the general public.

Without the benefit of this long-term planning, problems such as limited flexibility, high operating costs, unforeseen environmental problems, and revenue loss can be expected.

Planning is the whole key to reducing soil disturbance, both in the short and the long terms. You can't start your planning process early enough! The earlier you get on with it, the better off you'll be. It will give you the necessary time to ensure that your operations run efficiently and continue to make a profit.

The soil disturbance guidelines, in addition to all the other things you have to deal with, force you, as planners, to think in more than one dimension. For example, you need to think about:

**Engineering**

- Do I lay it out for skidders, crawler tractors, cable system, or a combination of all these?
- Where do I place the landings?
- What road density is required?

**Harvest timing**

- Winter logging reduces the total amount of soil disturbance and is reflected in the hazard rating. FERIC studies have shown that, although the trails are wider in winter during construction and skidding, the measured disturbance is less because there is less cutting into the bank, and in many cases over half the trail is built on snow.

  Another consideration is to delay harvesting an area until the right equipment is available.

**Silviculture**

- Is site preparation required?
- Is there access for crews to replant, space, or thin?
- Is debris removal required?

**Other resources**

- What wildlife species are present?
- Do they require special management?
- How long will reserve areas be necessary?
- Are there special features in the area that I should be considering, such as a rock formation or alpine meadows?

  The Ministry of Environment has several lists that will be helpful in planning for wildlife species. These include:

  1. Endangered species in Canada
  2. B.C. Red, Blue and Yellow lists

**Harvesting Methods/Equipment**

Within the context of soil disturbance, the "sensitivity rating" quantifies the maximum percentages of soil disturbance that will be allowed. These ratings really suggest the logging systems that should take place on a site.

On **very high** sensitivity rated areas, the sites have very high surface erosion and/or mass wasting and/or very high displacement hazard ratings. They occur on steep or very steep slopes having shallow soils. Road construction into these areas is prone to slope failure or extensive surface erosion. A regional soils specialist should be consulted. Should logging be allowed, the only option available is to use a cable logging system. Even then, there must be great care taken in the construction of landings and in harvesting.

Sites that are **high** sensitivity rated have one or more high hazard ratings and/or high compaction or surface erosion hazard. Summer ground skidding has the potential to cause large amounts of degradation. Road construction and logging on steep slopes may cause excessive soil displacement and on gentle slopes cause serious compaction or puddling. There are severe timber harvesting limitations and if ground-based skidding is to be used, it is recommended that it be done on a snowpack or frozen soil. Other options include use of low ground pressure equipment, designated skidtrails, or a cable system. When the total allowance is only 9%, there is little margin left for skidtrails if the landings take up 4%.

**Moderate** degradation sensitivity implies that ground skidding can cause compaction and puddling on gentle slopes and that soil displacement may occur on moderate slopes. Some restrictions on timber harvesting may include having to harvest on a snowpack or frozen ground, having to use wide-tired skidders or low ground pressure equipment, and having to minimize excavation during skidroad construction.

**Low** sensitivity site implies that there is a minor chance of degradation, as there is low mass wasting or displacement hazard and low to moderate compaction and surface erosion hazard. If logging is done under favourable conditions with adequate planning and supervision, normal logging with rubber-tired skidders are appropriate.

The choice of equipment also affects the degree of disturbance. On steep slopes there is no need to construct skidtrails with a large D7 or TD20, nor is it necessary to skid with a 528 or JD740 when cheaper equipment will produce just as effectively.

FERIC is aware of two companies that have opted for construction of skidtrails using a small backhoe. Although the costs are higher than for using a tractor, the total disturbed area is less noticeable because the bucket places the soil directly in front of the track and minimizes sidecasting. Another advantage of the hoe is its ability to push over a tree and align it easily for removal.

Probably the biggest danger of the interim soil disturbance guidelines is that they are applied to individual cutblocks and, therefore, cause us to think in terms of one cutblock at a time. This runs counter to the idea that more planning produces better logging operations. You should keep in mind that the main objectives of the soil disturbance guidelines are to encourage better planning and supervision.

Be careful you don't get into the trap of short-term planning, or only planning one cutblock at a time. For instance, you might find that by changing a cutblock boundary the block will fall within the acceptable soil disturbance guidelines — and this may be quite acceptable — but don't stop looking at this one block. You also have to look at all the adjoining blocks. The dollar you save today may cost you $5.00 on the adjacent block tomorrow.

Also, short-term planning can significantly increase future cable yarding costs. If you don't incorporate mid-slope roads for efficient cable logging into your plans now, you'll probably end up with unnecessarily high cable yarding costs in the future.

Approved haul roads are exempt from the guidelines. It behooves you to ensure you have effectively done your long-term planning so all future roads are identified. For instance, you may require a spur road to develop an adjacent block.

Long-term planning will also help ensure you get efficient road densities and spacing. It may also allow you to incorporate other resource values, at minimum costs. For instance, your long-term plan may show planned hiking trails that go through your cutblock. Well, why not plan your skidtrails on this same route and make it into a hiking trail — complete with culverts, signs, etc., after your harvesting is completed?

You not only get your timber, but you also get a high quality hiking trail for very little investment. This can be most effective if you've done sufficient long-term planning, and if you've allowed the public to be part of this planning process from the beginning.

Early planning will "red flag" areas that have high and very high sensitivities. This early knowledge allows you to consider alternative harvesting methods such as cable systems.

There's a general perception that cable systems are much more expensive than the conventional skidder and crawler tractor operations. This is not always true! FERIC studies of swing (grapple) yarders on coastal British Columbia have shown that grapple yarding bunched wood can be almost as cheap as using skidders. But, it also means using a feller-buncher, which will cause some soil disturbance. This alternative cable yarding system should be considered for some of your future logging.

Another area of opportunity is the use of mobile backspars in conjunction with the grapple yarder. If the site can be feller bunched then, in many cases, the mobile backspar can probably walk across the ground without the necessity of building backspar trails. If a fireguard is required, then might it be able to double as the backspar trail?

This early flagging, and early identification of the need for alternative harvesting systems, will also allow the accountants to plan for future capital investments. Good planning will ensure you have the right piece of equipment for the job, at the time you need it.

In summary, implementing soil disturbance guidelines is going to focus on a "block-by-block" development. It will be possible to end up making a decision on a single block, for short-term gain, at the expense of high costs and lost flexibility on an adjacent block. Watch out for this!

Early, long-term planning will help you recognize compromises that may be necessary. Planning allows you to be able to start discussion early in the process with others involved, such as the forests and environment ministries, and public groups such as the Guides and Outfitters and the Cattlemen's Association. Also, it allows you to plan for alternative harvesting methods and equipment needs. Efficient planning will highlight soil and site productivity conservation by giving you:

- fewer roads and landings;
- improved definition of problem areas; and,
- better scheduling of operations.

This will ensure you maintain overall efficiency and profitability of operations for the long term.

Soil disturbance guidelines can strengthen longer-term planning in that they state more explicitly the standards that logging operations will have to meet. These guidelines are very focused on soil. But, if you satisfy the soil resource guidelines, you've gone a long way in satisfying the requirements of all the other resources you must manage today. Thank you.

# SITE DEGRADATION AND IMPLICATIONS TO TSA PLANNING

Larry Price

Site productivity loss as a result of excessive soil disturbance is a growing forest management concern in British Columbia. Skidroad, landing, and road construction during timber harvesting commonly result in soil compaction and the removal of nutrient-rich surface soil horizons. Tree growth may be affected by decreased root penetrability, decreased aeration, and changes in the availability of moisture and nutrients. Tree growth reduction resulting from soil disturbance has been reported in a large number of studies (reviewed by Utzig and Walmsley 1988), but the variation in magnitude of reported growth losses is considerable. This variation may be explained in part by differences in the severity of disturbance or by the effects of accessory site factors which may amplify or mitigate the impact of soil disturbance (McNabb and Campbell 1985).

The recent Timber Supply Analysis in the Golden TSA has indicated a lack of reliable data for estimating long-term site productivity reductions. In the fall of 1986, regional research staff, in conjunction with district staff, undertook a study to measure the levels of soil disturbance associated with ground harvesting systems in the TSA. The primary objectives of the project were to:

1. estimate the amount of detrimental soil disturbance resulting from logging with summer ground skidding systems in the Golden TSA; and
2. evaluate the implications of the measured disturbance levels on the Golden TSA annual allowable cut (AAC) calculation.

Detrimental disturbance was defined as all soil disturbance attributable to skidroads with greater than 25 cm sidecut, all secondary roads, and landings. A total of 20 randomly selected, recently logged openings were sampled. Forest productivity reductions were estimated using the productivity loss co-efficients contained in the proposed procedures for implementation of the Ministry of Forests policy "Reduction of Productivity Losses From Logging Operations" (Ministry of Forests 1987).

Total detrimental soil disturbance from skidroads, secondary roads, and landings on slopes greater than 30% averaged 35%, with a resulting productivity loss of 19%. The range in total detrimental disturbance on these slopes was 23–52%. On slopes less than 30%, detrimental soil disturbance averaged 17%, with a productivity loss of 11%. The higher level of disturbance on the steeper slopes (i.e., 30%) resulted from the larger amount of skidroad disturbance noted on these sites. Skidroad disturbance on slopes greater than 30% ranged from 15 to 35%. This wide range of skidroad disturbance levels suggested that significant opportunity exists for minimizing disturbance through better harvest system design, better operator performance, or selection of alternative harvesting systems on difficult terrain. Most sites on slopes greater than 30% had an average skidroad spacing of less than one tree length. On all slopes, average landing area on cutblocks greater than 15 ha in size was 3.3%. Percentage of landing areas on smaller cutblocks varied with cutblock size (Thompson 1988).

This study demonstrated the feasibility of quantifying disturbance levels within Timber Supply Area planning units by means of random sampling. Further research is required to define productivity loss co-efficients that take account of the severity of soil disturbance and site-specific factors significant to tree growth.

A field workshop run July 17–18, 1987, evaluated the implications of the study and came to a consensus regarding the parameters of site degradation and future planning direction required. It was agreed at the workshop that forest land base productivity losses are being incurred as a result of forest harvesting operations. There is a recognized need for strategic planning at the branch, regional, and district levels to deal with harvesting-induced site degradation.

Two primary issues were identified concerning site productivity loss: control and accounting in timber supply analysis.

## Site Degradation Issues Identified At Golden Workshop

1. CONTROL

   **Options:**

   a) Sensitivity ratings:
      - Ecosystem-specific sensitivity rating development through ongoing pedology work. Sensitivity ratings such as those developed in the Kamloops Forest Region are too general to be meaningful on a site-specific basis.
      - Sensitivity rating development through consensus at the district level and mutually agreed to at the pre-harvest silviculture stage of TSA planning. The sensitivity rating would then be implemented into development and harvesting plans.
      - Co-operative planning and research on specific trial areas involving the Forest Engineering Research Institute of Canada, Ministry of Forests, and industry. This option would provide data on pre- and post-harvesting site productivity and economic implications of designated skidtrail layout.

   b) Education:
      More education is required on the implications of site degradation. This education should be directed toward industry and the Ministry of Forests, with primary focus on operators and field layout personnel.

   c) Soils inventory information:
      A more refined soils inventory is required to identify sensitive areas for incorporation into development planning.

   d) Harvesting Equipment:
      Future equipment purchases by industry should aim to reduce adverse site disturbance.

2. ACCOUNTING — TIMBER SUPPLY ANALYSIS

   There is provision under Section 56 of the *Forest Act* to reduce the Allowable Annual Cut.

   Site productivity losses must be incorporated into long-run sustained yield. Although net down figures need to be refined (as do sensitivity ratings), estimates based on best available knowledge should still be used.

   Two options exist for incorporating productivity losses into long-run sustained yield. Ongoing pedology work is required to fine-tune both options.

   a) Net down land base
      There was disagreement on netting down skidtrails (40%) and landings and secondary roads (100%), as timber production (although reduced) may occur on this land base. There must be differentiation of net down for summer and winter harvesting.

   b) Reduce site classes
      This option would not alleviate concern about the total loss, but it would reflect reduced yield on the affected land base.

## Co-operative Site Degradation Study

One option identified which would address the issue of controlling and accounting for harvesting-induced site degradation was a co-operative study involving the Canadian Forestry Service, Forest Engineering Research Institute of Canada, Ministry of Forests, and industry. This project would provide data on pre- and post-harvesting site productivity, as well as on economic implications of various harvesting methodology.

In the fall of 1987, the co-operative project received formal approval.

**The Study (FERIC Study Plan)**

This study will examine relationships between timber harvesting and soil disturbance, and related biological and economic concerns. It has two main components:

1. harvesting studies, which will analyze production, costs, and sources and levels of soil disturbance for a range of harvesting options and conditions; and
2. biological studies, which will characterize soil disturbance and site productivity relationships.

The objectives of the harvesting component of the study are:

1. to investigate options available for reducing soil disturbance associated with timber harvesting;
2. to quantify their production costs and soil disturbance levels; and
3. to describe their operational advantages and disadvantages.

The objectives of the biological component are:

1. to quantify the extent of, and changes in, soil surface characteristics and chemical and physical properties resulting from various forest harvesting systems and season of operation;
2. to monitor the effect these changes have on seedling establishment and long-term growth;
3. to establish site climate monitoring stations in each cutblock to isolate, as much as possible, the soil effects alone on tree growth; and
4. to monitor natural soil amelioration processes over time.

A range of summer and winter harvesting sites have been selected throughout the TSA which reflect various timber types, terrain, and soil conditions. It is hoped that the results will provide planning direction to other areas of the Nelson Forest Region and Interior.

The study will provide a starting point to implement site disturbance ratings that incorporate biological and economic factors.

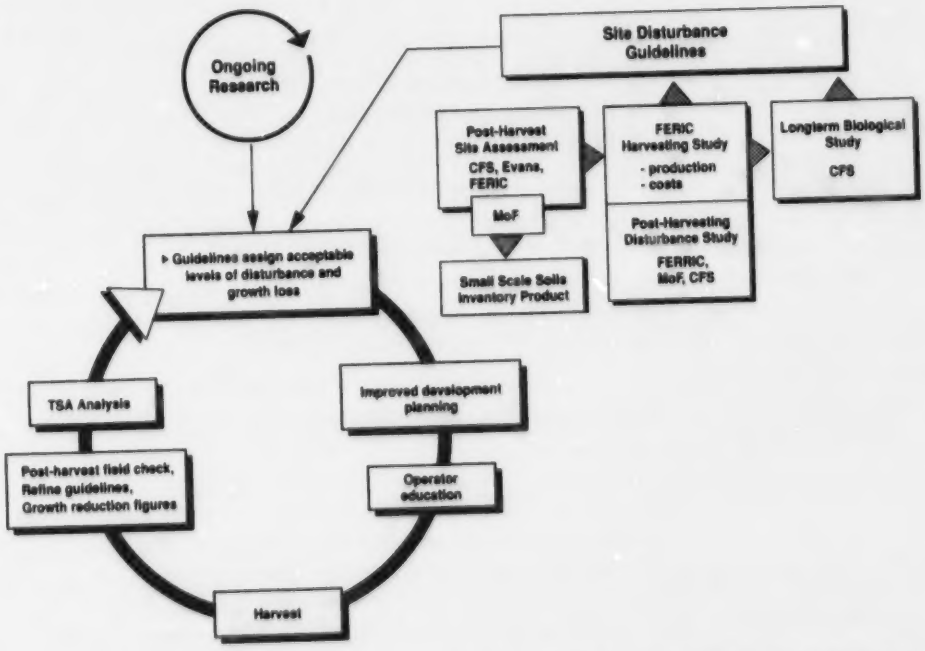


FIGURE 1. The site disturbance ratings are recognized as part of a dynamic process and may change with improved technology and biological data.

### TSA Planning and Site Disturbance

The site disturbance studies will provide improved information for the development of short- and mid-term integrated resource management (total chance) plans. These plans, once reconciled with the long-term management objectives, will form the framework of a resource management plan that projects volume availability in space and time which is linked to development and operational planning.

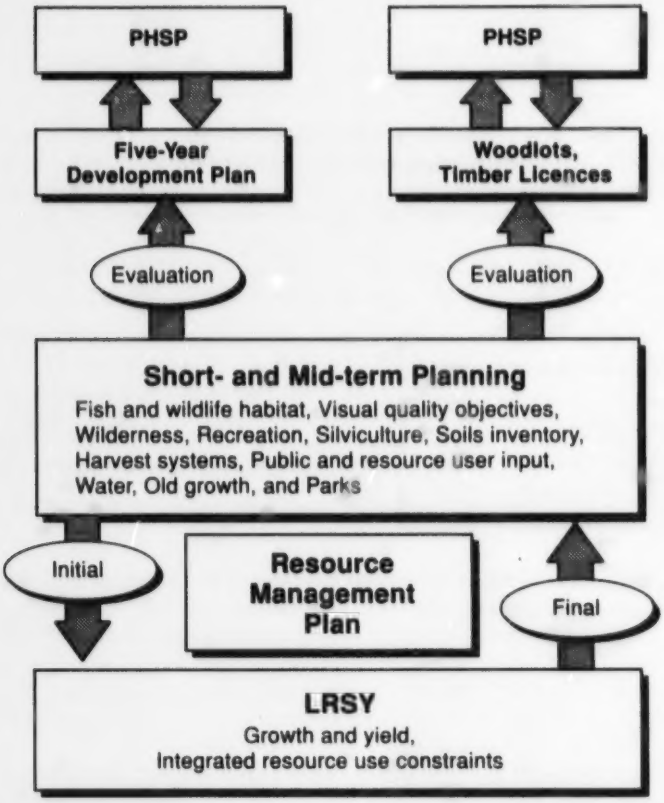


FIGURE 2. Resource management plans must be linked and provide direction to development and operational planning levels.

### Developmental and Operational TSA Planning Phases

Two aspects of TSA planning must be improved if harvesting-induced site degradation is to be minimized.

First, total chance integrated resource management planning is required on a drainage or defined unit basis.

Second, improved operational planning on a harvest block basis is also required. Operational planning would focus on such harvesting methodologies as designated trail layout, operator education, and equipment modification.

Site degradation target levels must be considered in relation to the silviculture system implemented on site. This will ensure that site impacts are considered not only at harvest, but at the post-harvesting treatment and beyond.

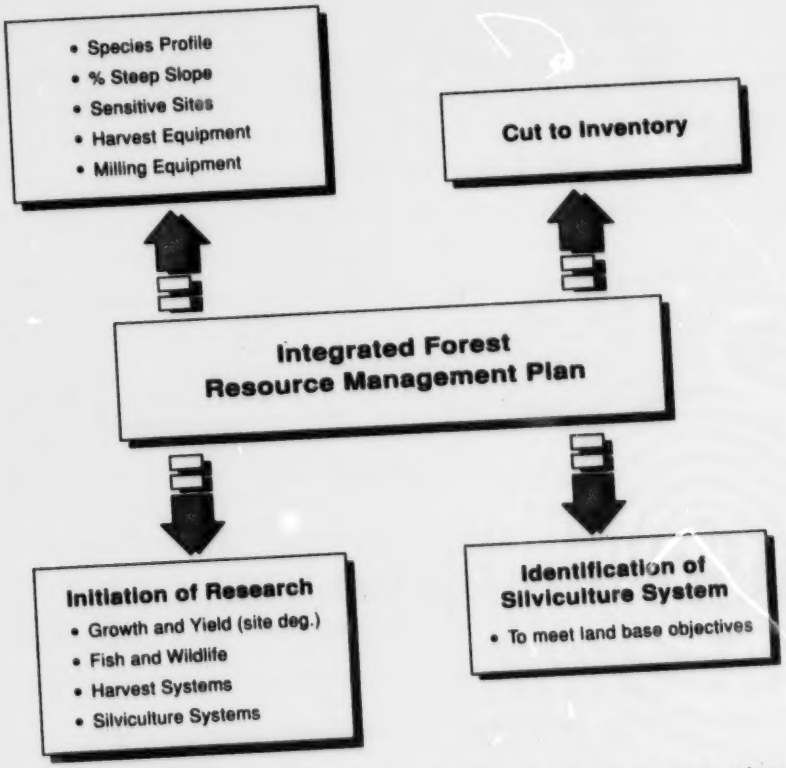


FIGURE 3. Resource management plans will provide direction to all agencies, industries, resource users and the public regarding forest management planning.

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# SOIL REHABILITATION AND APPRAISAL ALLOWANCES

Hubert Nyst

The Valuation Program consists of various functions:

- cruising
- revenue inspections
- export
- waste management
- audit accounting
- scaling
- appraisals

As requested, I will discuss, superficially, appraisals with you today. When I discuss appraisals with someone, I often see their eyes glaze over rapidly, a sign to me that I do not have their undivided attention. I also found out that actually very few people understand the concept and principles of the current appraisal system. I must admit that it is a complex issue.

I will tell you first what the appraisal system is not. It is not a goody bag used to put all the cost items in that someone making the cutting prescriptions can think of, and which you shake and a stumpage rate falls out.

We used to have this type of very site-specific appraisal system. It was called the "Rothery System," and was abandoned in 1987.

In 1987, the government signed an agreement with the Americans called a Memorandum of Understanding. This was essentially an agreement between the U.S. and us that we would increase our stumpage rates in return for the Americans dropping their tariffs on our lumber exports.

The Valuation Branch conceived an ingenious, simplified appraisal procedure called the comparative pricing system to accommodate the Memorandum of Understanding.

Well, it was a simple system when we first implemented it in 1987, but since then it has become more and more complex. It was based on the premise that the Crown would receive $500–600 million per year in stumpage revenue. This translates into a return to the Crown of approximately 6% on all lumber and wood products sold. The forest industry sales are valued at $9 billion per year. This, by the way, gives you an idea of the enormous economic importance of the forest industry in British Columbia. The whole appraisal system is based on a simple, short equation:

$$SR = BR + (VI - \overline{VI})$$

where: $VI = SP - OC$
$SR$ = stumpage rate
$BR$ = base rate quarterly adjusted
$VI$ = value index of cutting authority to be appraised
$\overline{VI}$ = mean value index also quarterly adjusted: it is the SP - OC for all permits in a similar timber type

The values for $\overline{VI}$ and BR are given to us by the Valuation Branch, so the only item we have to calculate is VI and that is what the appraisal calculation is all about. The $\overline{VI}$ value index is obtained from broad averaged cost experiences by the industry in specific forest types.

These costs are collected by the Forest Service from the licensees on a yearly basis and are averaged. The government counts on the VI and the $\overline{VI}$ neutralizing themselves so that the BR becomes the stumpage rate.

Every time someone puts an extra allowance in the appraisals, such as an allowance for push down logging, the VI increases and the stumpage rate decreases, leaving the Valuation Branch to scramble to make up the loss of revenue elsewhere in somebody else's appraisal. This is called the waterbed effect.

Therefore, it is important to remember that measures to reduce soil disturbances, for example, are implemented on a broad front so that the Forest Service can pick up these costs in the cost survey and identify the cost estimate for these measures in the appraisal manual. As long as these measures are carried out on an experimental basis, it will possibly not be allowed for the appraisals. It should be funded by Research.

We know the selling price of the products that can be manufactured from the timber on the site. Now we have to figure out what the operational costs are, using mostly broad average values for tree-to-truck costs, transportation costs, and milling costs.

The appraisal system appraises timber in the interior to the end-products of lumber and chips. The appraisal system does not charge stumpage on value-added products, such as veneer or sliced white pine, to provide an incentive for the industry to go into secondary manufacturing and enhance employment in the province.

This is as far as I want to go on appraisals.

I was requested to say something on two more subjects: one was landing rehabilitation, and the other one was domestic watershed allowances.

There is not really a lot to say about landing rehabilitation. The Appraisal Manual allows $0.09/m$^3$. This includes the cost of ripping and seeding. If the landings are to be planted, the area of the landings must be incorporated in the total area to be treated silviculturally.

Now onto domestic watershed allowances. It is our intent to protect domestic water supplies. To do this, we can insist, where required, on more and larger culverts, energy dissipation, the use of bridges instead of culverts, hydroseeding, end-hauling and cut and fill slopes at the proper angles of repose. This should be part of the planning stage of the integrated resource plan.

The appraisal allowances for this additional work varies from $3.55/m$^3$ in wet areas to $1.14/m$^3$ in dry areas. We have limited the site of the domestic watersheds to which we apply these allowances to 90 km$^2$.

The reasons for the size limitations are:

1. The impact of road construction on small watershed areas is greater than on larger ones.
2. Cutting permit areas can be better distributed in a large watershed.
3. The timber availability to amortize the roads is greater in large areas than in small ones.

# ALTERNATIVE SITE DISTURBANCE POLICIES: THE OREGON EXPERIENCE

Timothy E. Sullivan

The Malheur National Forest has been monitoring the impacts of ground-based yarding systems since 1981. Sampling guidelines developed by Region 6 have been used to determine if Regional Soil Protection Standards have been met. The sampling system provides a statistically sound evaluation of the impacts of tractor logging on the soil resource. Region 6 Soil Protection Standards are proving effective in protecting the soil resource on the Malheur National Forest.

## Objectives

My three objectives here today are to present:

1. a brief history of the Region's concern for soil resource protection;
2. Region 6 Soil Protection Standards; and
3. a summary of the results of the intensive soil monitoring conducted on the Malheur National Forest.

## A Brief History

Concern about the damaging effects of heavy logging equipment on the soil resource began in the 1950's. Steinbrenner (1955) and Steinbrenner and Gessel (1955) published a series of papers describing the effects of tractor logging on the physical properties of forest soil in southwestern Washington and on the regeneration of Douglas-fir. In 1959, Youngberg published a similar paper showing less leader growth (42% reduction) on a heavily disturbed skidtrail than where tractors were excluded. Froehlich (1978) reported a 29% reduction in height growth in 17-year-old Douglas-fir. Froehlich in 1979 reported a 6–12% reduction in the basal area growth of 64-year-old ponderosa pine. Wert and Thomas (1981) measured a 12% reduction in the stand volume of a 30-year-old Douglas-fir stand.

Froehlich and McNabb (1983), in a paper presented at the North American Conference on Forest Soils and Treatments, stated, "High organic-matter content and other inherent properties make Pacific Northwest forest soils generally low in bulk density, high in porosity, and low in strength. As a consequence, these soils are susceptible to compaction by tractive machines, and stand growth may be decreased from 5 to 15%. Natural ameliorative processes do not rapidly loosen compacted soil, and where it remains compacted, stand growth losses are measurable for at least three decades."

Robert Meurisse, in a presentation to the Regional Forester (Region 6, 1981), stated the following:

- The areal extent of compaction on tractor units in the Pacific Northwest ranges from 15 to 50% (I have measured areal extents of up to 70% on tractor units on the Malheur National Forest).
- Soil compaction can last 40–50 years and longer.
- Compaction affects both seedling establishment and growth.
- Several studies estimate a volume reduction of from 8 to 15% for Douglas-fir when 25% of a unit is compacted. Similar values are reported for ponderosa pine.

## Region 6 Soil Protection Standards

The policy emphasizes prevention over restoration. Objectives of the standards are to:

1. minimize soil loss due to detrimental compaction, displacement, puddling, severe burning, and surface erosion; and
2. have realistic measurable soil protection standards.

Each project Environmental Analysis will specifically address the potential for soil compaction, displacement, puddling, severe burning, and surface erosion. When detrimental impacts are likely to occur, alternative prescriptions will be developed and evaluated. Appropriate mitigating and rehabilitation measures will be planned when necessary.

**Standards**

Leave a minimum of 80% of an activity area in a condition of acceptable productivity potential for trees and other managed vegetation following land management activities. Surface soil conditions known to result in reduced productivity or loss of the productive land surface, and the accompanying criteria for determining when and where these conditions occur, are:

**Detrimental soil compaction**

- Volcanic Ash/Pumice Soils — An increase in soil bulk density of 20% or more from the undisturbed level.
- Other Soils — An increase in soil bulk density of 15% or more from the undisturbed level, a macropore space reduction of 50% or more, or a reduction below the 15% level as measured by an air permeameter.
- Detrimental displacement — The removal of more than 50% of the topsoil or humus-enriched A1 or AC horizons from an area of 100 $ft^2$ or more which is at least 5 ft in width.
- Detrimental puddling — Observed as vehicle tracks when soil is molded and when depth of rutting has reached 6 inches or more.
- Severely Burned — When the top layer of mineral soil has been significantly changed in colour, usually to red, and the next one-half inch blackened from organic matter charring by heat conducted through the top layer.

**Surface Erosion**

| Erosion Hazard Class | Minimum percent effective ground cover | |
|---|---|---|
| | 1st Year | 2nd Year |
| Low | 20–30 | 30–40 |
| Moderate | 30–45 | 40–60 |
| High | 45–60 | 60–75 |
| Very High | 60–75 | 75–90 |

**Assessment**

The total acreage of all detrimental soil conditions should not exceed 20% of the total acreage within the activity area, including landings and system roads. Consider restoration treatments if detrimental conditions are about 20% or more of the activity area.

**Monitoring Results: Malheur National Forest**

Intensive soil monitoring was initiated in 1981 to determine if Regional Soil Protection Standards were being met on clearcut units that had been tractor-logged and machine piled. Resource specialists were concerned that excessive soil compaction was occurring on tractor-logged units, many of which had been logged several times.

Twenty-eight cutting units have been monitored since 1981, covering a variety of soil types, timber types, and silvicultural prescriptions. One unit was sampled before any management activity, two units were sampled before and after logging, and two units were sampled twice after logging.

Soil compaction was the major detrimental soil condition encountered. Nineteen of the 27 logged units exceeded the regional soil protection standard, with another five units very close to the standard. The unit sampled before any management activity was less than 1% detrimentally impacted. The two units sampled before and after logging increased from 1 to 18% and from 16 to 30% of their areas detrimentally impacted. One of the two units sampled twice after logging was 28 and 39% detrimentally impacted; the other unit was 14 and 18% detrimentally impacted.

**Conclusion**

1. Units that have been logged more than once are typically excessively compacted.
2. Machine piling is a major contributor to excessive compaction.

**Discussion**

Management activities have been modified to reduce detrimental impacts. Mitigating measures include designated skidtrails, winching, winter logging, ripping, and mechanical treatment and burning of the slash.

Restoration (ripping) of excessively compacted units is a high priority.

# ECONOMIC IMPLICATIONS OF SITE DEGRADATION

Dan Peterson and Bill White

This paper provides a two-pronged approach to the question of soil degradation. The first part of the paper uses the MUSYC model to examine the economic implications of site degradation on a Timber Supply Area (TSA) basis. The second half of the paper examines the economic implications of soil disturbance guidelines from a microeconomics perspective, using standard neoclassical theory.

To examine the economic implications of site degradation, we need to expand the problem to a forest or TSA planning level. In this way, the trade-offs, in terms of costs, associated with additional harvest planning, site rehabilitation, or reduced productivity levels, can be approximated.

We determine these effects using the harvest scheduling model MUSYC (Johnson and Jones 1979). The MUSYC model follows a linear programming algorithm to optimize a specified objective function over a chosen time period. It is one of the tools the B.C. Ministry of Forests uses to evaluate possible allowable cut scenarios.

The forest level input to be used in the model will be a modified version of the Fraser TSA. Only those treatments required by regulation will be initially allowed within the model. Therefore, no forest management other than basic silviculture will be done. It is assumed that once an area has been harvested, it will be immediately replanted to the original species. Thus, harvest volume reductions will only be made to account for productivity losses. Costs for basic silviculture were taken from the Ministry of Forests and Lands annual report for 1987–88, the Vancouver Region. Total costs for survey, site preparation, planting, and manual brushing are assumed to be $1458/ha. Perfect sustained yield, or even flow, is assumed over the initial 100 years, with harvest fluctuations of 20% allowed over the remaining 15 periods. It is accepted, then, that any losses in future volumes as a result of reductions in productivity, will affect the volumes that can be harvested today.

The estimates of productivity losses are those approximated by Utzig and Walmsley (1988). Based on figures associated with the Vancouver Interior (Tables 5.3 and 5.5 in Utzig and Walmsley 1988), a weighted average was calculated to determine the percent of harvest area degraded across all harvesting systems. On average, 15% of any area was found to have been degraded. This value was then multiplied by the estimated growth reduction brought about by degradation caused by harvesting (Table 6.4 in Utzig and Walmsley 1988). We determined that approximately 7.5% of an area's productivity would be lost due to harvest degradation. Degradation due to site preparation was not included because there were no estimates for the Vancouver Interior.

Hammond (1988) estimates the costs of rehabilitating degraded forest soils to range from $2500 to $4000/ha based on 25–75% disturbance levels. Using the weighted average of 15% area degraded, it is assumed that rehabilitation to achieve 100% productivity will cost approximately $2000/ha. We arrived at this by extrapolating a plotted line through the given levels of degradation and cost to the 15% level.

Hammond (1988) also estimated the additional comprehensive planning costs required to minimize productivity losses. These costs range from approximately $200 to $400/ha. It is assumed for this example, given in the paragraph above, that an additional $400/ha in harvest planning cost would negate productivity loss. The discount rate used for our example will be 4%. This value is acceptable to the B.C. Ministry of Forests and has been substantiated by Heaps and Pratt (1989) as a reasonable social discount rate. Prices for timber harvested are based on average 1988 values for all logs and all grades and are assumed to be $49.34/$m^3$.

Five MUSYC scenarios were developed to show the effects of site degradation. The first two scenarios were done to display the effects of productivity losses on periodic harvests and long-run sustained yield (LRSY). Both scenarios retained an objective of maximizing volume over the initial 10 periods. When no productivity losses were included, LRSY equalled 12.334 M $m^3$ per period, or 1.233 M $m^3$/yr. The objective period harvest equalled 1.706 M $m^3$/yr. In contrast, when productivity losses were included for all regenerated areas, LRSY equalled 1.141 M $m^3$/yr and objective period harvest equalled 1.667 M $m^3$/yr. In other words, the LRSY is reduced by the 7.5% that was assumed as the productivity loss. The reduction in periodic harvest, however, is much less, at only 2.5%. The periodic harvest is buffered because of the old growth that is initially harvested.

The second set of two MUSYC scenarios was designed to show how productivity loss affects the value of the harvest, and to display the trade-off between additional harvest planning, productivity loss, and site rehabilitation. By changing the objective function to one of maximizing net present value, the model will begin to examine which treatment option provides for the greatest return over the objective period. The maximization period was changed to cover the entire 25 periods. This was to ensure that the model would opt for the best treatment alternative in terms of value rather than volume for the entire planning horizon.

The third scenario examined the cost of site degradation. When productivity losses were assumed to occur, the harvest for the initial 10 periods was 1.665 M $m^3$/yr. This is a reduction in harvest from the volume maximization scenarios, as we see the model trading off value for volume. Average net revenue per year over the planning horizon was $7.852 million, whereas the average net revenue when volume is maximized is $7.821 million, a difference of $30 000/yr.

The fourth scenario included harvest planning and site rehabilitation alternatives. The periodic harvest equalled 1.703 M $m^3$/yr; the average net revenue over the planning horizon equalled $8.010 million. As was shown in comparisons of the productivity loss scenarios, the volume harvested decreased slightly while the net revenue increased. Average net revenue for the first scenario was $7.829 million/yr, a difference of $181 000/yr. It was noted in this scenario that the model chose to perform the additional harvest planning at $400/ha. It also accepted very few productivity losses rather than do any site rehabilitation. As an adjunct to this scenario, the further MUSYC run was made. In assessing whether the model would opt to do site rehabilitation or to accept productivity losses, it was found that the periodic harvest was 1.682 M $m^3$/yr, and that the average net revenue was approximately $7.907 million/yr. This shows the extraordinary cost of site rehabilitation to pay off in certain circumstances, given the assumptions about price.

Clearly, then, including old growth and performing the analysis on a TSA basis rather than on a single site basis buffers the effects of productivity losses. The results also showed that planning is a more cost-effective option than site rehabilitation, though site rehabilitation can be justified in some cases.

We have already shown that future volumes and values will be reduced when logging practices reduce soil productivity. Because showing that a volume loss exists is only a small part of determining the economic implications of detrimental soil disturbance, value losses were also included. In the next section of the paper, we examine more closely the standard economic approach used to decide if investment in future site productivity is worthwhile. This will be followed by an examination of the likely economic impacts of soil disturbance guidelines.

Net present value (NPV) analysis is the tool most often used by economists to determine if investments that must be paid for today, though they will not bring returns until some later date, are worthwhile. The value of the future benefits are discounted using an interest rate that reflects the rate of return which could be achieved in alternative investments (in our paper, 45%). Given that returns from forestry investments are not forthcoming for many years, this criterion often measures forestry projects harshly. Routledge (1987), Bowden (1988), and Hickman and Jackson (1979) all show, using NPV analysis, that the private landowner has little financial incentive to maintain future site productivity. When an operator is on Crown land with no guarantee of future harvesting rights, the incentive would be even further reduced.

While financial analyses using NPV analysis are methodologically sound in many situations, they fall short in providing a framework for analysing situations characterized by constraints imposed by society's desire for environmental safeguards and implemented through government policy. When the public's values diverge from market-derived solutions, the economically efficient point of production is at variance with the financially efficient production point. The problem of detrimental soil disturbance can be demonstrated in this context using a production possibilities frontier.

There is a limit to what society can produce, and the production of one good requires the sacrifice of producing another. This is portrayed in Figure 1, which shows a production possibilities frontier. The line joining the axes represents the maximum achievable combination of goods A and B that can be produced given a set of input constraints. Unless we are producing at a point inside the boundary (C), more of one good can be

produced only if some production of the other good is foregone. Points beyond the boundary (D) are not attainable given current resources and technology. Points such as E and F are both efficient in production. A criterion is needed to allow us to rank or judge the goodness of each combination of outputs, to decide which one is best. In market economies it is usually the price mechanism that determines the appropriate allocation of resources and the resulting best point on the production possibility frontier. For example, a point that maximizes the value of production could be chosen. When the price mechanism fails to provide a suitable resource allocation because there are too few actors (because of a monopoly, cartels, etc.) or all the costs are not borne by the decision maker, a situation called market failure exists. Government intervention through regulation is often used to determine the appropriate resource allocation in cases of market failure. The criterion is usually, but not exclusively, normative and should reflect society's norms and values. Through market forces, government regulation, or a combination of the two, a point on the curve can be defined as the economically efficient level of output.

The problem of detrimental soil disturbance can be demonstrated on a production possibilities frontier as shown in Figure 2. The horizontal axis represents forest product values attainable from the forest resource; the vertical axis represents on-site soil productivity and other environmental values (wildlife, water quality, etc.) on and off site.

Given this set of points to choose from, a private operator on private land, interested only in the financial aspects of the soil degradation question, would likely find it optimal to produce at a point at or near the horizontal axis. This reflects a lack of financial incentive to invest in off-site values or future site productivity. The same operator on Crown land with no guarantee of future harvesting rights would have even less incentive to prevent detrimental soil disturbance. In each of these cases the point on the curve chosen by the operator as economically efficient may not be in harmony with society's norms and values. These values can be imposed on the operator on Crown land through regulation.

The line ZZ' represents some minimum level of environmental values that society is willing to accept. The economically efficient level of production is not constrained to be a point on the curve above Z'. Moving up the curve, away from the original market-determined point of economic efficiency, will have an effect on both the individual operators and society as a whole. The decision that the operator now faces in light of increased costs is no longer "Do I want to preserve soil quality on this site?" as it was in the previous cases, but rather "Do I want to log this site or not?" Future values no longer enter into the decision.

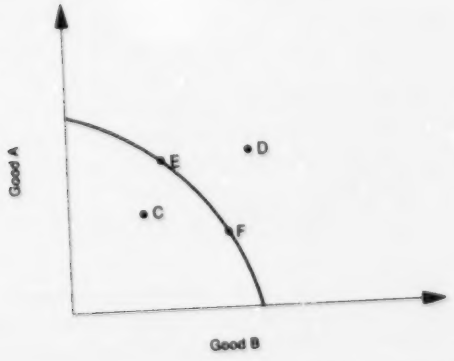


FIGURE 1. The production possibilities frontier.

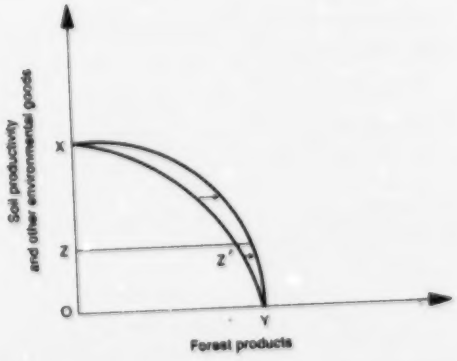


FIGURE 2. Production possibility frontier for the forest resource.

Given existing technology at the time regulations are imposed, operators would certainly not find it financially feasible to log all the sites they would have in an unregulated setting. The move up the production possibility frontier means that the economic timber supply today will be reduced through efforts to preserve tomorrow's crop or to minimize off-site damage. Sacrificing the benefits to society from the forest products foregone in favour of environmental values is the cost society chooses to pay. Since society has willingly chosen this trade-off, the resulting output is deemed to be economically efficient.

Market forces will not move the operator to gain back at least a portion of the forest product values that have been taken from him. This will also be in society's interest as long as the level of post-harvest soil productivity and other environmental values are retained. This can be shown on the production possibility frontier (Figure 2) by shifting the curve outwards, while keeping it anchored on the same endpoints. Now more forest products can be produced at each and every level of environmental values. In practical terms, this can be accomplished with modifications in technology. The financial incentive now exists to create cost-effective harvesting systems that retain soil productivity and reduce off-site risks, thereby retaining a portion of the economic timber supply. Developments in this area include a move to better planning of forestry operations (Hammond 1988), increased use of small rubber-tired and high flotation skidders or skidders equipped with wide low ground pressure tires, and greater use of excavators rather than bulldozers to construct roads and remove stumps (Smith *et al.* 1989).

Society's desire to have healthy forests for future generations is being met by both regulation and market forces. Government soil disturbance guidelines ensure that future site productivity is retained; market forces protect forest product values through new harvesting and site preparation technologies. The result should be an economically efficient balance between soil productivity and other environmental values and forest product values.

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# CONCLUDING REMARKS

Gerry Still

Sustainable development refers to any development that can be sustained in perpetuity by the environment (i.e., without degrading the capability of the environment to support that development continuously). Maintenance of site productivity is a prerequisite for **sustainable timber productivity** and sustained rates of harvest. Hence, the concern for soil disturbance and site degradation. If timber harvesting occurs without regard for maintenance of productivity, then harvest levels will decline. Timber management must be a **maintenance** activity, not just a resource extraction activity.

The real and potential effects of indiscriminant soil disturbance on other forest resources must be understood, including effects on: water quality, fish habitat, and the aesthetic or recreation resource. These resources are sustainable resource development opportunities as well. The public now expects timber management to be undertaken with sensitivity to these other values. If more appreciation for the soil resource and other related forest resources is not emphatically demonstrated, allowable levels of harvest in some parts of the province will be reduced as a result of public pressure.

Three other major issues must be addressed in the near future if continued progress is to be made.

- **Training**

A recent questionnaire circulated by the Interior Forest Harvesting Council Technical Advisory Committee (IFHC TAC) suggests that ministry and industry staff are not uniformly aware of existing soil disturbance guidelines, or do not interpret the guidelines uniformly. This means there is a need for a training effort to improve awareness. Machine operators and contractors need to get basic soil management information. Training is also required so that the soil disturbance measurement methodology is implemented consistently and appropriately on a province-wide basis. A standardized soil disturbance measurement methodology manual for British Columbia will be finalized soon.

- **Administrative Procedures and Guidelines**

The most critical need is for clear administrative guidelines. For example, Carr and Lewis noted that questions about how to choose blocks for sampling are common, and the proposed penalty mechanism is unclear. These issues, and other related ones, will be addressed at an upcoming IFHC meeting.

- **Research and Development**

Much research and development work is required. We need to be able to model or predict productivity impacts resulting from different types of soil disturbance. We also need to develop and experiment with different harvesting equipment and planning systems to meet soil disturbance guidelines and to accommodate the wide variety of site conditions and economic constraints present throughout British Columbia. We need to understand actual and potential site impacts.

One of the most pressing needs is for feedback about the appropriateness of existing guidelines, because if they are too lax or too stringent, then they must be changed. In this regard, we need not only operational feedback, but also research field measurements.

All of these areas of concern are currently being addressed, to some extent, by British Columbia researchers, and a number of tools and methods are currently under development.

Soil disturbance guidelines for mechanical site preparation are being developed, as are fireguard guidelines. Some work is taking place on the development of an air photo method for estimating soil disturbance.

We have also accomplished a lot in the last few years: numerous research studies, conferences and workshops have been organized; a soil disturbance measurement system has been developed, which is now the standard for the province; Interior soil disturbance guidelines have been introduced; a number of field keys have been developed for assessing potential disturbance caused by mass wasting, erosion, soil displacement and compaction; a series of training courses has been administered; and finally, the role of soil disturbance on present and future timber yields is starting to be reflected at TSA and TFL planning levels.

In summary, while much progress has been made on a number of issues related to soil disturbance in the province, there is clearly a need for more training and research, and for clear administrative direction.

## POSTER SESSION

# RAINFALL SIMULATION RESEARCH

Paul Commandeur

Soil infiltration capacity and the potential surface soil erosion response to forestry practices is assessed in rainfall simulation experiments. This research is largely exploratory at this stage and has been field tested at only one interior site (Cariboo Region). Treatments have included clearcut with humus layer intact, fireguard surface, and prescribed fire impacted sites. Additional rainfall simulation tests will be conducted during the summer of 1990 at a coastal site and an interior site. Examples of the infiltration response on a skidroad surface and on a slashburned site are presented below.

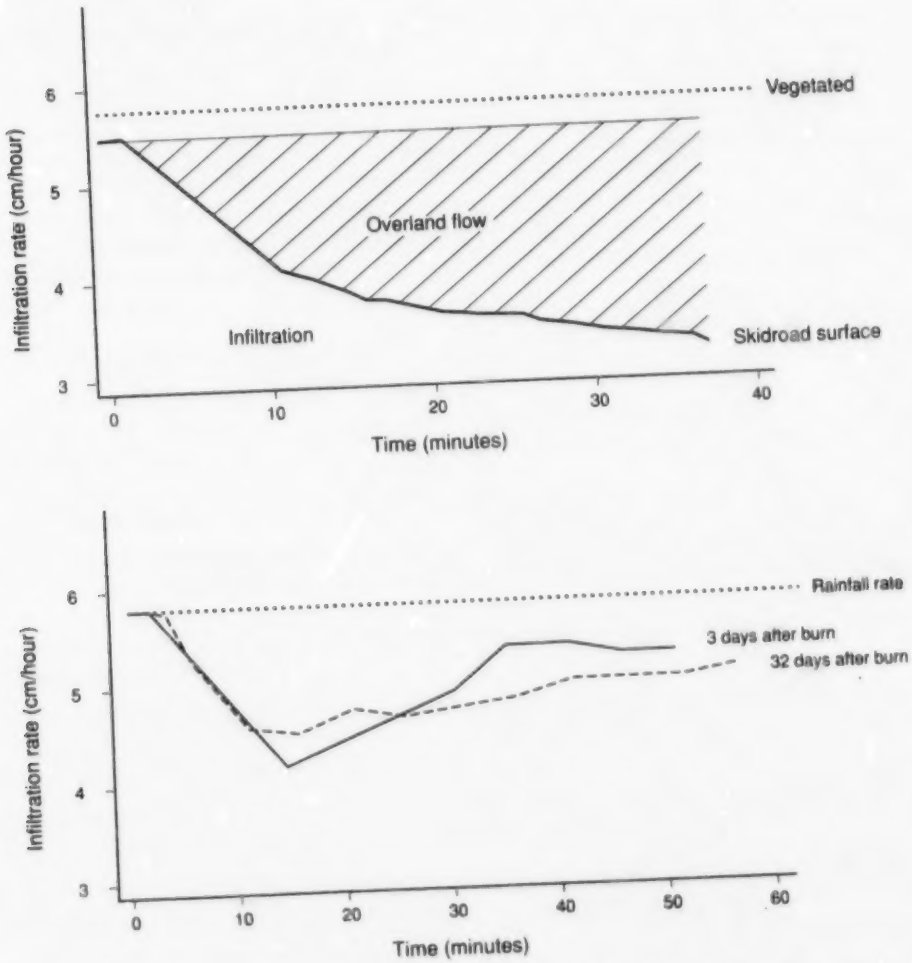


FIGURE 1. Infiltration rate on vegetated plot and skidroad surface (top). Infiltration response on "high" intensity slashburned site (bottom).

# THE IMPACT OF BIOMASS HARVESTING ON SOIL DISTURBANCE AND SURFACE SOIL EROSION

Paul R. Commandeur and Mark E. Walmsley

This study is funded by the energy from the forest (ENFOR) program of Forestry Canada. The ENFOR program is concerned with the impact of biomass harvesting on the environment, but site-specific field research in this area is largely lacking. Biomass harvesting has the potential to increase the severity and extent of soil disturbance resulting from ground skidding.

The objectives of the study are to determine the degree to which biomass harvesting would lead to a reduction in the ability of soils to resist surface soil erosion, and to determine the amount of surface erosion that can be attributed to such a reduction.

The study area, located in the Interior Cedar Hemlock Biogeoclimatic Zone in the Central Interior of British Columbia, was conventionally harvested using rubber-tired skidders during the fall/winter of 1987–88. Three treatments were established and consisted of conventional, biomass and unharvested conditions. Three plots in each treatment were set up as "mini-drainages," the boundaries of which represented, as best as possible, natural topographic breaks. A skidder was used to remove an additional amount of woody material from the three biomass plots.

A post-harvest soil disturbance survey revealed that, on average, the biomass harvest plots had 63% total soil disturbance (12% skidroads, 44% skidtrails, and 9% other) as compared to 47% for the conventional plots (34% skidtrails and 13% other). Sediment dams were erected along the contour at the base of each plot. Pins inserted in a grid pattern in front of the dams have been used to make sediment deposition measurements as a function of time. In addition, three erosion bridges were installed on each plot and will provide a measure of net erosion of deposition at these sites. The erosion measurements will be collected through the fall of 1990 and will be summarized in a final report.

Site preparation in the form of prescribed fire was conducted at the site in late spring of 1989 before planting. The opportunity therefore exists to compare the pre- and post-fire effects on soil erosion. Using a rainfall simulator, infiltration capacity experiments were conducted both before and after the burn, on vegetated areas, skidroad surfaces, and one section of a fireguard. In general, the results of these infiltration tests indicate that soil infiltration capacities exceed typical rainfall intensities for the site (highest rainfall intensity recorded to date was 20 mm/hour). Spring runoff as the snowpack melts may result in overland flow and surface erosion, but this possibility has not been validated at this site. Upon completion of the study, a comparison of soil erosion by treatment type will be made, and relationships between sediment yield and parameters such as precipitation, soil type, and infiltration capacity will be explored.

# COMPUTER DIGITIZATION AND DIGITAL IMAGE ANALYSIS FOR ASSESSING SOIL DISTURBANCE ON CLEARCUTS

Y. Jim Lee

Certain types and degrees of soil disturbance resulting from harvesting activities in turn result in soil degradation, and thus in reduced future productivity for trees. The present method of survey, a ground-based "grid-point intercept" system, is time-consuming and costly. The development of remote sensing techniques alone for estimating soil disturbance on the majority of clearcuts would result in greatly increased efficiency and reduced costs. Aerial photography is an appropriate vehicle for determining the area of well-defined disturbance such as those caused by landings, roads and skidroads constructed on bare ground. Skidtrails and winter-constructed skidroads often have narrow surfaces obscured by woody debris. Special remote sensing techniques can be used to estimate these less defined types of disturbance.

Aerial photographs and ground survey data for a recent clearcut were processed by a digital image analysis system, and estimates were made of the proportion of the ground surface in landings, roads and skidroads. These estimates were compared with the ground survey data. Preliminary work conducted on 1:5000 colour aerial photography from the Cariboo Lake area in south-central British Columbia indicated that, with operator assistance, the digital imaging process resulted in estimates of the extent of disturbance close to those obtained by a ground survey.

An advantage of the computer digitized image data was that one could use the principal component enhancement analysis to produce a best image feature channel, extracted from the three original red, blue and green channels, with emphasis on the study area. One could then assign a different colour for each of the three channels — the best image feature channel, the red and green channels — to obtain the best combination of colour and brightness for the image. This best colour image was used for performing the necessary digital image analysis. This could not be done on aerial photographs.

The use of computer digitized image data also allows the estimation of areas of landings, roads, skidroads, exposed compacted mineral soil and exposed mineral soil or woody debris. Pixel sizes of these disturbed areas can easily be calculated on the Perceptron image analysis system with this technique within a matter of hours. The savings in time and cost to survey soil disturbance on clearcuts will be substantial in the long run for the forest industry.

# EFFECTS OF WIDE-TIRE SKIDDER TRAFFIC ON SEVERAL VANCOUVER ISLAND FOREST SOILS

T.P. Rollerson

This study was designed to assess changes in soil bulk density, evaluate soil disturbance, and estimate the expected effect on site productivity associated with wide-tire skidder traffic on five Vancouver Island forest soils over a range of soil moisture conditions. A second objective was to establish baseline sites suitable for evaluating the growth of conifer seedlings on compacted soils. In general, soil bulk densities increased with increasing skidder traffic; the effect was more pronounced at higher soil water contents. The results did not vary dramatically from site to site. Soil disturbance, in the form of rutting and exposure of mineral soil, increased with increasing traffic and was generally more pronounced under moist soil conditions. The compactive effect of the wide-tire skidder is at the lower end of the range of compactive effects reported for ground-based yarding equipment, but is still expected to have a negative effect on seedling height growth. The sites were planted with conifer seedlings in the spring of 1989. The growth of these trees will be monitored for at least 5 years.

# EXPERIENCE WITH RETROSPECTIVE AND PLANTATION GROWTH STUDIES ON HARVESTED AND SITE-PREPARED CLEARCUTS IN BRITISH COLUMBIA

John P. Senyk and Rick B. Smith

Research and survey over the past 15 years have elucidated some relationships between soil disturbance and soil degradation. This has allowed regional estimates of productivity losses, in terms of wood volumes, to be made.

Retrospective studies give a quick approximation of tree growth responses, where the disturbance remains recognizable for at least 15 or 20 years after operations cease. They do not, however, adequately explain the history of the forestry operation, the environmental conditions during the life of the trees being measured, or the rate and causes of mortality.

Retrospective studies, carried out on skidroads ranging in age from 8 to 20 years, showed that negative effects of soil disturbance on tree growth was most common, but that enhanced tree growth was also possible under some conditions. Productivity losses of up to 15% occurred on some cutblocks, while in a few rare instances, growth enhancement, as high as 22% in one case, occurred on others.

Plantations, established specifically for determining the impact of harvesting and mechanical site preparation on tree growth, range up to 8 years of age. Unlike retrospective studies, plantations allow the researcher to control: species, time of establishment, spacing, planting spots, and competing vegetation. Tree mortality rates and causes can be determined and environmental parameters (e.g., soil and climate) measured initially and monitored in the long term to determine natural changes. It is also possible to relate tree growth to a specific machine and impact level in controlled experiments. The chief disadvantage is the long-term nature of the studies and high costs of maintenance.

The following table (based on Forestry Canada trials located in various parts of British Columbia) is a comparison of height and diameter growth of trees planted on disturbed (e.g., skidroad and skidtrail surfaces) and on adjacent, undisturbed soils.

| Estab. no.** | Age (yrs) | Species | Treatment | Disturbance category | Height and diameter relative to undisturbed*** | |
|---|---|---|---|---|---|---|
| | | | | | Dia. % | Ht. |
| 1) | 8 | Doug. fir | Stumped | Scalp | - 14 | - 13 |
| | | Lodge. pine | " | " | + 8 | - 3 |
| | | Doug. fir | " | Track | - 23* | - 24* |
| | | Lodge. pine | " | " | - 8* | - 10 |
| | | Doug. fir | Stumped/raked | Rake | - 3 | - 8 |
| | | Lodge. pine | " | " | + 8 | + 2 |
| | | Doug. fir | " | Track | - 27* | - 39* |
| | | Lodge. pine | " | " | - 6 | - 11 |
| | | Doug. fir | Non-stumped | Track | - 7 | - 7 |
| | | Lodge. pine | " | " | - 4 | - 6 |
| 2) | 8 | Doug. fir | Stumped/deep | Scalp | +41* | +36* |
| | | W. larch | " | " | +39* | +27* |
| | | Doug. fir | " | Track | +41* | +32* |
| | | W. larch | " | " | +19 | + 6 |
| | | Doug. fir | Stumped/shallow | Scalp | +20 | + 6 |
| | | W. larch | " | " | +25* | + 8 |
| | | Doug. fir | " | Track | +13 | - 2 |
| | | W. larch | " | " | +18 | + 6 |
| | | Doug. fir | Stumped/raked | Rake | + 4 | + 6 |
| | | W. larch | " | " | + 8 | - 5 |
| | | Doug. fir | " | Track | - 4 | - 13 |
| | | W. larch | " | " | + 1 | - 12 |
| 3) | 5 | Doug. fir | Stumped | Deposit | - 1 | 0 |
| | | Lodge. pine | " | " | - 5 | - 2 |
| | | Doug. fir | " | Track | - 4 | - 7 |
| | | Lodge. pine | Stumped | " | - 7* | - 9* |
| 4) | 4 | Doug. fir | Stumped | Deposit | +11* | + 8* |
| | " | " | " | Track | + 8 | + 4 |
| 5) | 5 | Doug. fir | Skidroad | Inner track | - 18* | - 33* |
| | | Lodge. pine | " | " | - 24* | - 32* |
| | | Doug. fir | " | Outer track | - 2 | - 14* |
| | | Lodge. pine | " | " | - 6 | - 14* |
| | | Doug. fir | " | Berm | - 2 | - 11 |
| | | Lodge. pine | " | " | - 7 | - 12* |
| | | Doug. fir | " | Sidecast | 0 | - 4 |
| | | Lodge. pine | " | " | - 2 | - 4 |
| 6) | 4 | Doug. fir | Skidroad | Surface | - 4 | - 17* |
| | | Lodge. pine | " | " | 0 | - 7* |
| | | Doug. fir | " | Berm | + 9* | 0 |
| | | Lodge. pine | " | " | + 9* | + 1 |
| | | Doug. fir | " | Sidecast | - 15* | - 21* |
| | | Lodge. pine | " | " | - 20* | - 15* |
| 7a) | 2 | | Skidtrail 740 JD + 640 LGP | Track 30-40 turns | | |
| | | W. hemlock | " | " | - 14 | - 32 |
| | | Doug. fir | " | " | +23 | - 2 |
| 7b) | " | | Skidtrail 740 JD | Track | | |
| | | W. hemlock | " | 100+ turns | - 52 | - 52 |
| | | " | " | 60–70 turns | - 41 | - 42 |
| | | " | " | 30–40 turns | - 37 | - 49 |
| | | " | " | 10–15 turns | - 25 | - 28 |
| | | " | " | < 5 turns | - 34 | - 37 |
| | | | 640 JD LGP | | | |
| | | W. hemlock | " | 100+ turns | - 33 | - 53 |
| | | " | " | 60–70 turns | - 10 | - 40 |
| | | " | " | 30–40 turns | - 17 | - 38 |
| | | " | " | 10–15 turns | + 1 | - 14 |
| | | " | " | < 5 turns | - 6 | - 20* |

* Mean height or diameter of trees for the disturbance category is significantly different than for the undisturbed. No statistical analysis available for Establ. No. 7.

** Establishment No.: 1) Gates Cr, Southern Interior (SI); 2) Phoenix, SI; 3) Marl Cr, SI; 4) Shawnigan Lk, Southern Coast (SC); 5) Marl Cr, SI; 6) Clearwater, SI; 7) Worthless Cr, SC: 7a-Lower Terrace; 7b-Upper Terrace.

*** Growth rate more (+) or less (-) on disturbed soil compared with that on undisturbed soil.

# GROWTH OF JUVENILE ENGELMANN SPRUCE ON SKIDROADS (ESSFc NELSON FOREST REGION)

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Soil degradation and subsequent losses in forest productivity, are major concerns in British Columbia. Forest harvesting is the main cause of soil degradation, and guidelines have been developed to limit the amount of severe soil disturbance. In the Nelson Forest Region, skidroads are the most common source of this type of soil disturbance. In this study, we sampled trees on older skidroads to provide estimates of these growth losses.

Engelmann spruce growth on skidroads was sampled on two sites in the Moist Engelmann Spruce Subalpine Fir (ESSFc) biogeoclimatic subzone of southeastern British Columbia in 1988. The two sites represented the extremes of elevation in this subzone: 1555 m (Eleven Mile) and 1890 m (La France). Both sites were on a northeastern aspect with a typical, rooting zone soil of gravelly sandy loam textured morainal and colluvial material, derived from local bedrock typical of the respective mountain ranges (sedimentary at La France and granitic at Eleven Mile). The average moisture regime was submesic at La France Creek, and mesic-submesic at Eleven Mile Creek. Localized seepage was present in both areas.

Trees were sampled from specific **disturbance classes** that were shown by previous research (Smith and Wass 1979) to have different impacts on growth: skidroad inner track (IT), outer track (OT), sidecast (SC), and undisturbed (UU). At each site, a total of 192 naturally regenerated trees were sampled, 48 trees from each disturbance class. Post-harvest silvicultural treatment was limited to spot burning at La France Creek. No treatment occurred at Eleven Mile Creek.

At age 12, the trees were generally taller on the low elevation site, as expected (Figure 1). At both sites, the **percentage differences in total height** and 3-year increment between the disturbance classes were similar (Figure 1). Relative total height and 3-year increment on a rank order basis was:

$$UU \equiv SC > OT >> IT$$

Three-year increment was significantly lower on the inner and outer track at both sites (Figure 1), suggesting that currently observed reductions in growth will become larger in the near future, and possibly in the long term.

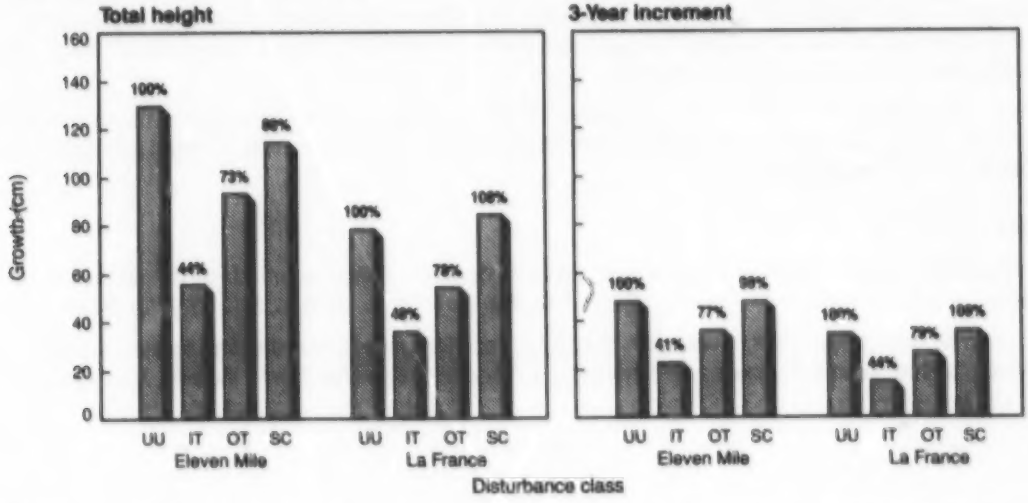


FIGURE 1. Total height and 3-year increment at 12 years of age. Percentages above bars are relative to the undisturbed (UU = undisturbed; IT = inner track; OT = outer track; SC = sidecast).

The main factors causing growth reduction were inferred to be soil compaction and nutrient depletion due to soil displacement during skidroad construction. The largest reductions occurred on the inner track, where the combined effect of compaction and displacement was greatest. The least severe type of disturbance was in the sidecast, where the 3-year increment was almost identical to that in the undisturbed trees at Eleven Mile, and slightly greater than that in undisturbed trees at La France. The higher sidecast 3-year increment at La France Creek was attributed to three factors: 1)increased soil temperature; 2) reduced levels of competing vegetation; and 3) lack of compaction. Soil temperature was assumed to be a major growth limiting factor at this high elevation, north-facing site.

Comparison of trees on these sites with untreated, undisturbed trees may underestimate potential growth reductions caused by soil degradation. Site preparation resulting in a reduction of vegetation competition and surface soil mixing may have improved undisturbed tree growth at both sites due to an increase in soil warming and incorporation of organic matter. Disruption of natural drainage due to skidroad construction may also have decreased available moisture for undisturbed trees.

In a previous study of Engelmann spruce on skidroads in southeastern British Columbia, Smith and Wass (1979) found both enhancement and reduction of growth. On non-calcareous soils, growth of sidecast trees was consistently increased. Inner track growth either decreased, or was not significantly different, and outer track growth increased, decreased, or did not change, depending on the site. In general, the results of the current study show greater height growth reductions on the skidroad surface than were previously measured. A comprehensive review of soil disturbance growth effects can be found in Utzig and Walmsley (1988).

## Conclusions

Conclusions of this study were:

1. Soil compaction and soil displacement significantly reduce growth at both sites. The greatest reductions occurred where the combined effect of both factors was greatest.
2. Twelve-year-old outer track trees are 22–27% shorter than undisturbed trees. Growth will be reduced by an even larger percentage in the near future, and possibly in the long term.
3. Trees on the inner track are 56–59% shorter than undisturbed trees at age 12. It is unlikely that inner track trees will be merchantable at the rotation age of cutblocks. The larger reduction in inner growth was due to the combined effects of soil compaction and gouging greater than 25 cm deep.
4. Sidecast growth depended on the site. In the cold environment at La France Creek, tree growth at 12 years age was slightly improved in the sidecast. At Eleven Mile Creek, growth was slightly reduced. The differences were not statistically significant in either case. Sidecast and undisturbed tree growth is expected to be similar in the near future.
5. Trees at least 15–20 years old must be sampled to provide more conclusive forecasts of rotation age growth effects. For the trees measured in this study, approximately 40% of total height growth occurred in the 3 years before sampling.

## References

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